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DEXTER S. KIMBALL, CONSULTING EDITOR

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INDUSTRIAL ENGINEERING AND MANAGEMENT

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INDUSTRIAL ENGINEERING AND MANAGEMENT

Problems and Policies

BY

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PREFACE

This volume has been developed in the belief that the fundamental principles of industrial engineering and management can be presented most clearly and can be made most serviceable through the supplementary use of examples and cases taken from industry itself. For the student, a study of actual problems in their natural setting appears to be the most interesting and effective way of presenting the basic factors involved.

The plan of this book has been, first, to state clearly the principles that govern the subject discussed, and then to bring in concrete cases from successful manufacturing and business concerns to illustrate these principles.

The author has not confined himself to extremely simple illustrations but has gone to some length in his efforts to present rather full and complete examples of the basic principles involved. This fullness of treatment has made it impossible to cover in this single volume the entire field of industrial engineering and management; for example, it has appeared inadvisable to include the subject of personnel administration.

The author for a number of years has had intimate contact with industry and has personally selected or developed much of the case material used for illustrations in this volume. Furthermore, this material, in mimeographed form, has had actual use in the classrooms of two universities.

The first six chapters with Appendices A and B are devoted to the treatment of the design and equipment of the factory, while the remaining seven chapters with Appendices C and D cover important phases of the measurement and the compensation of human effort, together with closely allied subjects.

The chapters on time and motion study and those on the point system of wage payment should prove of particular value to industrial executives and engineers.

For classroom use, actual manufacturing data taken from a well-known industrial concern have been included in Appendix A. These may be used as the basis for many of the problems designated to accompany each of the chapters of the text. The

data are so arranged that problems such as those of factory layout and equipment may either be extended throughout a semester or be covered in a much shorter space of time.

Over the period of several years during which this book has been in process of development, the author has had constant assistance and advice from industrial executives and educators. To these he would here express his great indebtedness. His special thanks for assistance received are due to Mr. B. C. Heacock, president of the Caterpillar Tractor Company, and to Mr. W. C. Randall, chief engineer for the Detroit Steel Products Company. Likewise to Messrs. Virgil M. Palmer, J. R. Shea, F. E. Darling, N. D. Hubbell, Dwight Vandevate, and Professor A. G. Anderson is he particularly obligated for valuable criticism and much original illustrative material which have greatly aided in the development of the text.

RALPH M. BARNES

IOWA CITY, IOWA,
June, 1931.

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CHAPTER I

THE DESIGN AND CONSTRUCTION OF FACTORY BUILDINGS

The factory building is designed to house the equipment and processes of production; therefore, the selection of the type of building and the materials of construction is closely connected with the problem of laying out the equipment which will be used inside the building.

Types of Factory Buildings.

Factory buildings are of either the single-story or the multistory type. A combination of these two forms of buildings is, however, commonly found. Single-story buildings permit better natural lighting, facilitate the movement of material within the building, reduce fire hazards to a minimum, permit the location of all materials and equipment on the ground floor which eliminates the question of permissible floor loads, and in many cases provide a simpler method for expansion when this becomes necessary.

Multistory buildings, on the other hand, reduce the land cost per square foot of floor space approximately in the same ratio that one bears to the number of stories; and consequently multistory buildings are necessary where land costs are high. The cost of roof and foundations may favor the multistory building. There are many manufacturing processes that require multistory buildings, as, for example, flour mills, starch plants, and industries in general where gravity can be used to great advantage in the movement of materials from one process to another.

Effective Floor Areas.

The single-story building gives more effective floor areas than can be expected from a multistory building. The effective floor area of a building as compared with its gross area depends upon thickness of walls, wall columns, size and spacing of interior columns, and the extent to which the gross area is reduced by stairways and elevators and space required for access to them. Dimensions for the gross area of a building are commonly taken from the outside face of wall columns but not including any small projections beyond the face of the wall columns.

The following data[1] show effective floor areas in a single-story building as compared with a multistory building of similar size and design.

" . . . a very practical and detailed comparison was developed by William R. Fogg, secretary of The Ballinger Company, and other members of the staff, for a large manufacturing company which was about to make a choice between leasing a one-story suburban plant designed and to be constructed for their specific occupancy, and leasing an equivalent amount of space in a large loft building which was about to be erected, and which the owners were willing to modify to a reasonable degree to meet the manufacturer's requirements. In both cases the manufacturer had practically an ideal layout offered him (within the limits imposed by each type of building) and in both cases a lease was contemplated, so that exact dollars and cents comparisons could be made of most of the items which had a bearing on the choice to be made. . . .

"The multistory building was to be a typical high-grade central loft building of 10 stories divided into two huge wings with a wide light court in between. . . . The second floor, lighted in the center by skylights in the court, and extending throughout both wings, had an undivided area of over 90,000 sq. ft. Each wing contained about 33,800 sq. ft. above the second floor, so that occupancy of the entire second, third, and fourth floors in both wings gave a gross floor area of approximately 231,000 sq. ft. . . . Floors were designed to carry 200 lb. per square foot; column spacing was approximately 20 by 25 ft. on centers; elevators were provided for the exclusive use of the tenant of the lower floors. . . . The building was to be of reinforced concrete con-

[1] ROGERS, TYLER S., One-story or Multistory Factories. Which Is Cheaper to Operate? *Mfg. Ind.*, vol. 14, No. 5, p. 361, November, 1927.

struction and its design was the last word in structures of this type.

"The single-story plant was to be a modern brick, steel, and concrete saw-toothed building of approximately 200,000 sq. ft. The columns were 20 by 40 ft. on centers, and the saw-tooth skylights gave a glass area of over one-third the floor area.

"In a one-story building the gross area of the building would be reduced by the width of the walls . . . this area may be taken as 1 ft. by the perimeter of the building.

"In a multistory building, an allowance must be made for the thickness of the wall columns which project inside the building.

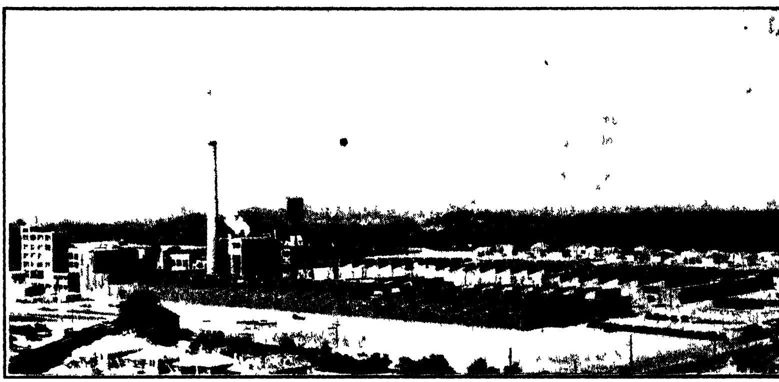


FIG 1.—Single-story building with saw-tooth roof construction, erected for The American Chatillon Corporation, manufacturers of Rayon. (*Courtesy of Lockwood Greene Engineers, Inc.*)

These wall columns would average approximately 18 in. thick for a three-story building designed for 200 lb. per square foot and average 2 ft. thick for the second, third, and fourth stories of a 10-story building designed for the same loads. Loss due to walls would, therefore, be 2 ft. by the perimeter of the building.

"In the one-story building, the structural steel columns for 20- by 40-ft. spans would be 8 in. square, with an area of approximately ½ sq. ft. This area times the number of columns would determine the reduction in the gross area due to columns.

"In the multistory building, the average diameter of the concrete columns would be 27 in., or 5 sq. ft. This area times the number of columns would determine the reduction of the gross area due to columns. There would probably also be a further reduction of effective area due to these large columns by reason

of their interference with the arrangement of lines of machines, which, however, it is not possible to calculate in advance of making a machine layout. . . .

"Stairways are assumed to be 10 by 20 ft. long, or an area of 200 sq. ft., plus an allowance of 50 per cent for access to them, making a total of 300 sq. ft. Three stairways have been assumed as being required in the east and three in the west section of the proposed loft building."

The following data summarize the unavailable floor area for the single-story and the multistory buildings:

FLOOR AREA COMPARISON OF PLANTS

Single-story building

		Square feet
Total floor area	380 × 560 =	212,800
Perimeter	1,880 × 1 =	1,880
Columns	234 × ½ =	117
Four entrances, access areas at 100 sq. ft. each		400
		2,397 unavailable

$$\frac{2,397}{212,800} = 1.12 \text{ per cent of floor space unavailable.}$$

Multistory building

			Square feet
	Total floor area		231,000
A.	Second story	423 × 217 =	91,791
	Deduct for through elevators		1,791
			90,000

Unavailable floor area:

		Square feet
Perimeter	1,280 × 2 =	2,560
Stairways	300 × 6 =	1,800
Elevators	160 × 4 =	640
Columns	160 × 5 =	800
		5,800

$$\frac{5,800}{90,000} = 6.4 \text{ per cent of floor space unavailable.}$$

FLOOR AREA COMPARISON OF PLANTS.—(*Continued*)

		Square feet
B. Upper stories	231,000 − 90,000 =	141,000
Typical upper story		33,840
Unavailable floor area:		

		Square feet
Perimeter	1,006 × 2 =	2,012
Columns	60 × 5 =	300
Stairways	300 × 3 =	900
Elevators	160 × 2 =	320
		3,532

$\frac{3,532}{33,840}$ = 10.4 per cent of floor space unavailable.

	Square feet
Unavailable floor area for 2d floor	5,800
Unavailable floor area for upper floors, 141,000 at 10.4 per cent	14,664
	20,464

$\frac{20,464}{231,000}$ = 8.8 per cent average unavailable floor area for multistory building.

SUMMARY

Type	Gross area	Net available area	Unavailable area
Single-story building	212,800	210,403	2,397 (1.12%)
Multistory building	231,000	210,536	20,464 (8.8 %)

Cost of Artificial Light.

A single-story building with saw-tooth construction of proper design will provide adequate natural lighting for a majority of the working days of the year. In the case of a multistory building, it may be necessary to use artificial illumination in the interior of the building unless the ceilings are high and the width of the building narrow.

The Ballinger Company estimated that the single-story building mentioned above would require 150 hr. of artificial lighting per year if the plant operated from 8 a.m. to 5 p.m. during the week and from 8 a.m. to 12 o'clock noon on Saturdays; while in

the case of the multistory building it would be necessary to maintain artificial illumination in the central part of some of the area during the entire day.

The current cost plus lamp renewals as well as power costs for the elevator service is summarized as follows:

Type	Light, kilowatts	Elevator power, kilowatts	Current cost	Lamps	Total
Single-story building	63,840	None	$ 1,756	$ 280	$2,036
Multistory building	560,025	54,000	16,886	2,084	18,970

Types of Construction.

The various types of construction used in industrial buildings may be classified as follows:

1. Mill construction.
2. Structural steel construction.
3. Reinforced concrete construction.

Mill Construction.

Mill construction consists of brick or masonry walls with the interior made of heavy wood timbers. The columns and girders are spaced close enough so that by laying heavy plank diagonally over the girders there will be sufficient strength to carry the floor load, which seldom goes above 100 to 150 lb. per square foot. Mill construction, while not fireproof, may be termed "slow burning," and when it is further protected by an overhead sprinkler system it is very satisfactory for two- or three-story buildings as far as fire hazards are concerned.

Structural Steel Construction.

Structural steel construction is used for single-story buildings where it is desirable to use roof trusses of long spans. The tendency is toward the use of larger floor areas free from supporting columns. Figure 2 shows a common type of single-story building using steel construction with 50-ft. spans, that is, with one row of columns down through the center of the building 100 ft. wide. Walter R. Eberhardt of The H. K. Ferguson Company states that it would be possible to provide a building of the same width and height with the same stresses and material specifi-

cations but without the interior columns for approximately an additional cost of 20 cts. per square foot.[1] He further states that a single-story building 60 ft. wide with a row of columns

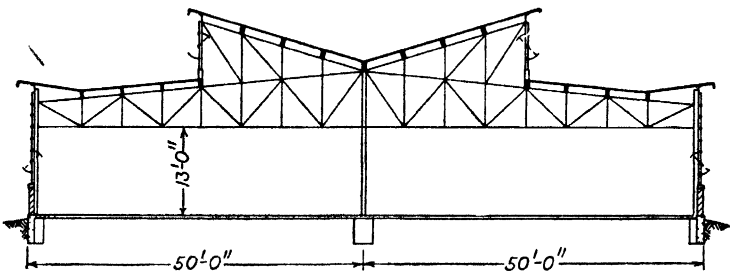


FIG. 2.—Single-story building with two 50-ft spans

down the center would cost about 10 per cent less than a building of the same width with a clear span. A building 120 ft. wide with a row of columns down the center would cost roughly about

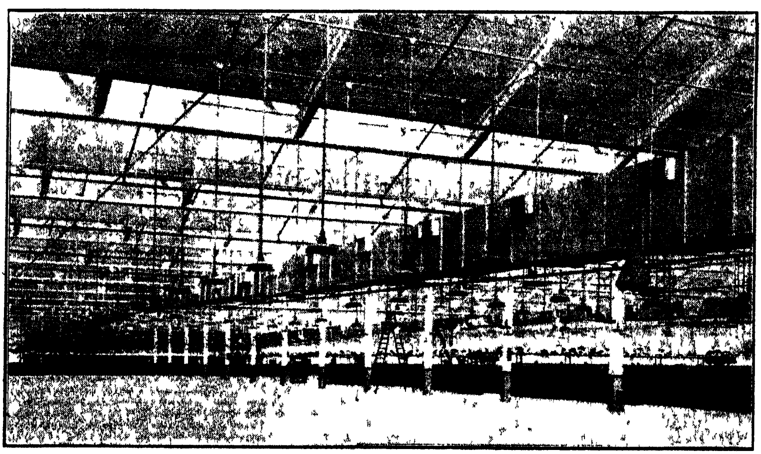


FIG. 3 —The interior of a single-story building of the American Enka Corporation By use of clear span roof trusses, large floor areas free from columns may be obtained. (*Courtesy of The H. K. Ferguson Company.*)

16 per cent less than a building of the same width with a clear span roof truss.

[1] EBERHARDT, WALTER R., How Much Does a Column Cost? *Cross Section*, vol. 3, No. 12, p. 10, The H. K. Ferguson Company, December, 1929.

Structural steel construction is also used for multistory buildings where heavy loads and long floor spans are desired, or where tall buildings with relative light floor loads are needed. With proper fireproofing around the steel work a structural steel building is as nearly fireproof as can be designed.

A Multistory Factory Building.

Figure 4 shows the exterior of a factory building recently designed and built by the Otis Elevator Company at their Yonkers works. The building has four stories and a basement and

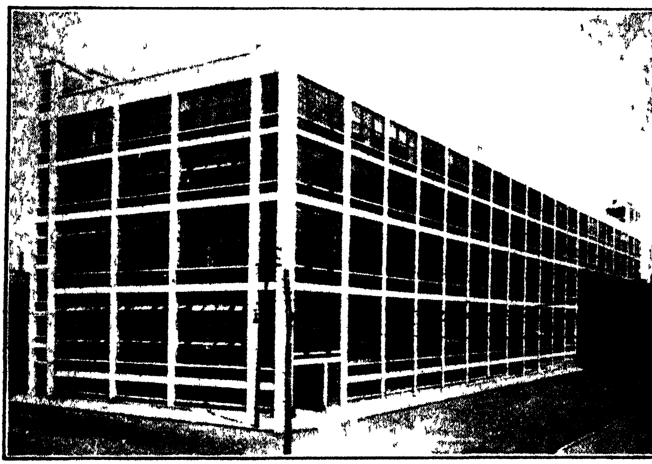


FIG. 4.—Side view of the Motor Manufacturing Building at the Yonkers works of the Otis Elevator Company.

covers an area of 350 by 100 ft., or a total of 153,000 sq. ft. The basement and three lower floors are devoted to manufacturing electric motors and other equipment used on elevators, while the top floor, or works office, houses an office force of 200. Eight hundred shop workers occupy the factory building proper.

W. O. Moyer, building engineer and architect for the Otis Elevator Company, describes this building as follows:

"The building fronts on three streets with the fourth side adjoining neighboring property. Two light courts extend along this side between the spaces occupied by three elevator and stair towers.

"In each story except the basement the building is three bays wide for the total length of 350 ft. These bays are 28 ft. 10 in

wide and the column spacing lengthwise of the building is at 17-ft. centers. The construction is of steel, with exterior columns and beams cased in concrete. Walls are of face brick between floors and window sills.

"Floors are reinforced concrete 5 to 6½ in. thick, as required, to carry the weight of equipment. Floor loads and ceiling heights of each story are given in Table I. The first three stories

TABLE I.—FLOOR LOADS AND CEILING HEIGHTS

Floor	Safe load, pounds per square foot	Ceiling height,[1] feet
Basement...............	...	10½
First floor...............	600	24
Second floor.............	500	20
Third floor..............	250	14
Fourth floor.............	125	12

[1] Dimensions include floor thickness, except in the case of the basement.

and the basement are occupied by manufacturing departments and store rooms, respectively, and the top floor is used for the works offices. A special hardener was used to finish the factory floors, while a colored granolithic waxed topping was used for the general office floor.

"In the basement are kept the stocks of materials and supplies used for motor manufacture. Heavy machinery is installed mainly on the first floor. . . .

"The building has four entrances, one at each corner. One of these admits to the main lobby, and a passenger elevator at this point serves all floors. Another entrance, under the tower, at the right in Fig. 4, leads from the street to a large freight and passenger elevator of a capacity and size to handle the largest electrical industrial truck which the company operates. Alongside of this entrance is a doorway admitting trucks to the first floor. The entrance shown at the center of Fig. 4 admits trucks to the basement on a platform 3 ft. above the floor level. Incoming supplies are placed in storage here, and heavy equipment is lifted by crane to the first floor through the well above the entrance. The door at the far left in Fig. 4 admits to a fire tower in which a stairway leads up to all floors. Just back of this stairway is a combined freight and passenger elevator,

and at the middle of the building on this same side is a similar elevator and a fire tower with stairway.

"The building thus has one passenger elevator and three combined freight and passenger elevators, each large enough to hold an industrial truck and several people; also three stairways, all in fire towers. For additional safety, a bricked-in passageway connecting with a middle fire tower leads through the basement across the building to the side street for emergency exit.

FIG. 5.—Lamination Manufacturing Department, first floor of the Motor Manufacturing Building, Otis Elevator Company.

Windows, Doors, and Partitions.

"Through the entire building all the window sash are of steel. Factory-type sash are used in all stories except the fourth, or office story. In factory-type sash the lights are 14 by 20 in. and are obscure glass with the exception of the two lower rows, which are clear glass. Wired glass is used on the side which adjoins other property.

"The windows in the office story are solid metal double-hung windows, with single large panes of plate glass.

"All doors throughout the building are fireproof, either hollow metal or tin clad, except those leading direct to the streets. The lobby entrance and the rear entrance doors have upper panels of glass. The basement truck entrance and the freight elevator entrance at the front of the building have power-operated rolling steel doors.

"Doors leading to the executive offices and also to stairways throughout the building are of hollow metal. Elevator doors are of the vertical-lift type, except for the passenger elevator, which has horizontal sliding doors. All elevators are, in addition, equipped with safety gates.

"The building has a flat concrete roof, with tar and felt covering, and is surrounded by a 4-ft. concrete parapet. . . .

"Few partitions are used in the building. Where required in the shop, they are of 6-in. hollow tile. The vaults have brick walls. Ovens are self-contained and are of steel. Dipping tanks are enclosed by partitions of metal lath and plaster carried on

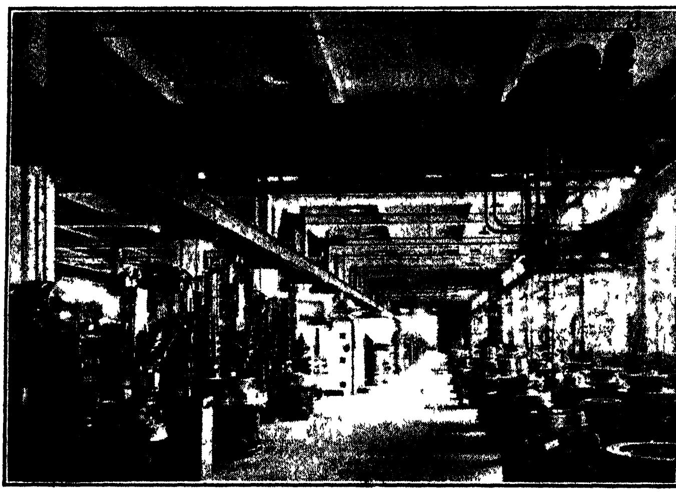


FIG. 6.—Machining and commutator assembly department, second floor of the Motor Manufacturing Building, Otis Elevator Company.

steel framework. This construction provides safety in case of explosion, because the partitions would merely bulge and no particles of masonry would be thrown around the room. Office partitions are of 4-in. gypsum block plastered in three-coat work.

"Stairways in the fire towers consist of cast-iron abrasive safety treads, on steel framework, and are equipped with galvanized pipe handrails. Landings are of concrete.

"Heating is by means of a vacuum system. Exhaust steam from the company's power house is piped to the building through an underground tunnel. All steam mains are insulated. Wall-type radiators are used throughout the factory and offices. . . . Thermostatic control regulates the heating.

"The building is well protected against fire. All materials used in its construction are fire resisting and further protection is secured by means of equipment. A complete sprinkler system has been installed. Hand extinguishers are located at accessible points throughout the entire plant. Hose lines have been put in according to a system laid out by the insurance company.

"The building has been designed and departments were laid out and equipped to provide every facility for rapid, straight-line flow of work, high quality and low cost of production, and minimum handling of parts and materials."[1]

Reinforced Concrete Construction.

Reinforced concrete construction is widely used for factory buildings where rigidity and permanence are of prime importance. This type of building has the disadvantage of requiring relatively large columns, and consequently it has a high percentage of unavailable floor area in comparison with a structural steel building. Depreciation and maintenance costs are low and this type of construction is economical from the point of initial cost.

The two main types of reinforced concrete construction are flat-slab and beam-and-girder designs. Figure 7 shows the interior of a reinforced concrete building of flat-slab construction. This type gives the best appearance, permits windows to extend to the ceiling level, diffuses and reflects both natural and artificial light better, and permits shafting and other equipment to be placed nearer the ceiling than does the beam-and-girder type of construction.

The plain unfinished exterior of a reinforced concrete building does not present a very pleasing appearance, although it has been widely used in past years. The present trend is away from the use of concrete alone for exterior walls. All brick, or brick and cast stone, is commonly used now, although brick with exposed concrete columns would be less expensive.

Architectural Design of Industrial Buildings.

As a machine is designed to perform a specific kind of work, so the industrial plant exists primarily to serve a functional

[1] MOYER, W. O., New Otis Building Efficiently Planned, *Mfg. Ind.*, vol. 12, No. 6, p. 413, December, 1926.

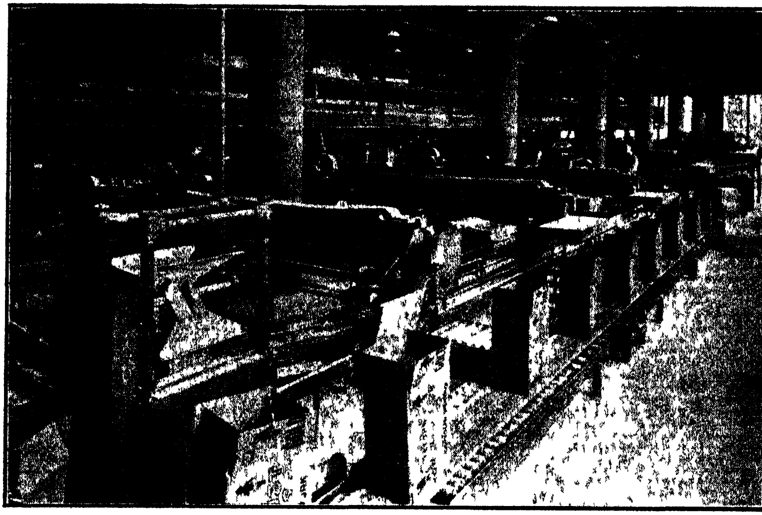


FIG. 7.—Packing department of the Gold Dust Corporation showing reinforced concrete building, flat-slab construction The packages are filled in the machines shown in line at the left, fed from storage by the belt conveyor running above. Another machine places the packages in cartons and delivers the cartons to a conveyor which carries them to a machine that closes and seals them and drops them into the spiral gravity chute which leads to the shipping and storage departments on the first and second floors This picture illustrates the importance of proper column spacing and structural proportions to allow space for the efficient arrangement of equipment. (*Courtesy of Lockwood Greene Engineers, Inc.*)

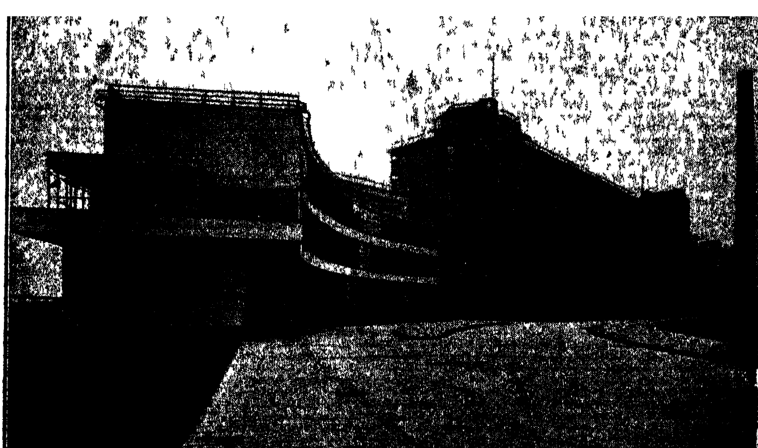


FIG. 8.—The van Nelle Tobacco Factory at Rotterdam, showing the European trend in industrial building design. (*Courtesy of Cleome Carroll.*)

purpose. The factory building must first satisfy the requirements for which it is to be used. An industrial enterprise oper-

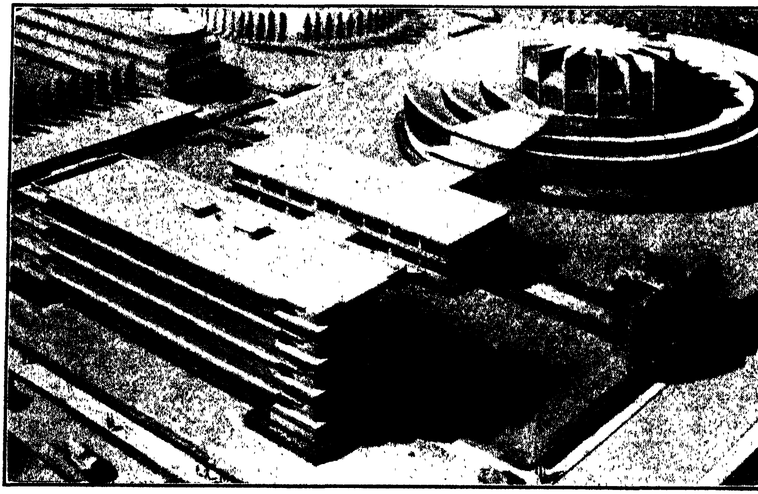


Fig. 9.—Proposed plant for the Toledo Scale Company. Precision devices group, showing the circular machine shop, the connecting corridor, the receiving, shipping and storage building and the laboratory. (*Courtesy of the Toledo Scale Company, Norman Bel Geddes, Architect.*)

ates for profit and it is unwise to add an excessive burden to the capital investment by erecting factory buildings that are architecturally elaborate and costly.

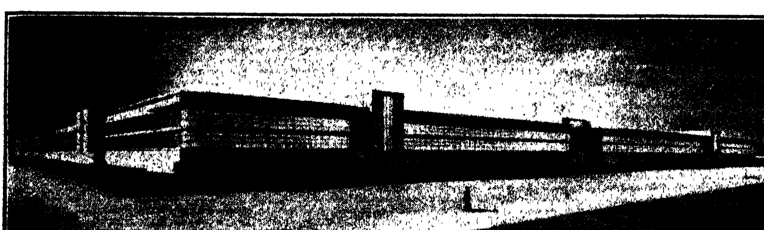


Fig. 10.—Proposed plant for the Toledo Scale Company. Scale factory, a monitor-type building with walls entirely of glass. Roofed with alternate high and low bays that afford adequate light. (*Courtesy of the Toledo Scale Company, Norman Bel Geddes, Architect.*)

This does not mean that factory buildings should be ugly; on the contrary, a pleasing appearance is worth having. If a building is designed first to serve its purpose, it is not difficult,

through the use of architectural skill and the wide variety of materials now available, to give it fine proportions, proper balance, and attractive color. Industrial buildings may be made extremely imposing, and this is to be recommended when no great addition in cost is involved.

Owners and managers are anxious to have attractive factory and office buildings, employees prefer them, and the advertising value of a plant with agreeable proportions and a pleasing appearance is not to be overlooked.

CHAPTER II

THE SELECTION OF EQUIPMENT

KIND OF EQUIPMENT

The selection of factory equipment might be discussed under two headings: first, the kind of equipment and, second, the amount of equipment required. The selection of equipment should be intrusted to individuals who are properly equipped to perform the task—men with considerable shop experience, a technical knowledge of the processes and methods of manufacture, and a thorough understanding of the different kinds of equipment available for use. In some cases it becomes necessary to design special machines and equipment for certain processes and operations. It is apparent that there is a very close relationship between the design of the product and the manufacturing processes involved. The designer must work and cooperate with the production manager. The substitution of new and more efficient equipment is a process which is constantly taking place in all factories.

In factories already in operation, machine tools and equipment are purchased (1) to replace those which are worn out, (2) to improve the quality and increase the quantity of output, and (3) to bring about lower production costs.

Replacement Due to Wearing Out.

With the continual changes and improvements in machines and processes, it is often necessary to substitute newer machines for those in use long before they are actually worn out. However, many types of standard machines have to be replaced. Even though the machines are kept in repair, there will come a time when it is no longer profitable to make additional repairs. One manufacturer makes the following analysis when any extensive repairs are contemplated on a machine: An estimate is made of the proposed repairs and then the question is put, "If this machine were offered for sale by a second-hand machine-tool dealer, would we purchase it at the value now on our books and

then make the repairs as estimated?" Often this will show that it is not economical to make additional repairs.

Since obsolescence is such a large factor in some industries today, many manufacturers have the policy of crowding the machine to its maximum limit, expecting that by the time the machine is worn out another newer and better one will be available, which would necessitate the replacement even though the machine were in good condition. Other concerns do not think it best to run machines above the limit set by the manufacturer and particularly is this true on standard machines. This policy seems to be more nearly representative of factories in general, since there is a decided saving in repairs.

Added Equipment to Get Increased Output.

When business is increasing rapidly, it is the problem of the executive to decide whether to purchase additional equipment in order to supply the demands for his product, to run night shifts if this is not already being done, or to let the work out to other firms. When new equipment is purchased to supplement that already in use, it is often duplicate, but more often it is best to purchase semiautomatic or automatic machinery, particularly when it is apparent that there will be an increasing demand for the product. By the use of such machines, greater transfer of skill is effected and fewer workmen are needed. The whole process of manufacturing may be speeded up with the result that the amount of goods in process will be decreased. When new equipment will improve the quality of the product, it is very often purchased even though no saving in cost is made.

Replacement and Additions of Equipment for Lower Costs.

New equipment will be used when greater economies in manufacture will be effected thereby. The continual advance in machine design and the rapid progress in new time-saving processes make it necessary very often to replace tools and machines with new ones long before they are really worn out. Obsolescence is one of the biggest factors to be considered. Machines and equipment become obsolete for several reasons:

1. A change in the method of manufacture may require different equipment. The use of a steel stamping instead of a casting will require the addition of a press. A grinding operation may be more desirable than a turning or a milling operation, which

would make the purchase of a surface grinder or a cylindrical grinder necessary.

2. New designs in equipment make the present machines obsolete. More rigidly built machines permit heavier cuts and give greater accuracy or better finish. Quick-return tables or better methods of lubrication or quicker set-up are points of advantage in the newer machines. Two very recent developments might be mentioned here. First, the use of cemented tungsten carbide tools to replace high-speed steel; and, second, the extended use of hydraulic feed mechanisms on machine tools. S. Einstein, chief engineer for the Cincinnati Milling Machine Company, gives the following points in favor of the use of hydraulic transmission:

"Summing up the advantages of hydraulic transmission, it might be said, first, that it gives an infinite selection of speeds or feeds; second, it protects the machine and tools from overloading and breakage; third, it provides ease of control; fourth, it gives greater tool life, due to its cushioning ability of absorbing shocks; and fifth, it makes the automatic change of feed or speed rates easily possible. Taking all of these advantages into consideration, it can readily be assumed that the hydraulic transmission will be more and more popular in machine tool applications . . .

"To illustrate the growth in the productivity of machine tools, there is given a comparison of methods for splitting and straddle-milling operations on connecting rods, from 1910 to 1930. These data express in terms of productivity the development which has taken place, not only in improvements on the machines, but also in the improvement of the method for producing these parts.

Date	Description	Production per hour
1910	4 pieces held in special fixture on table.	40
1915	3 pieces held at each end of hand-index base	60
1920	6 pieces held in removable work-holding unit; load extra work unit while milling....................	90
1926	4 pieces held in hand-index fixture..................	110
1928	4 pieces held in automatic-index fixture...........	125
1929	4 pieces held in automatic-index fixture.............	140
1930	8 pieces held in automatic-index fixture.............	248

"Another good illustration showing the increase of productivity of the modern machine tools in the grinding of valve tappets is as follows:

Date, up to	Description	Pieces per hour
1920	Center-type grinding[1]	90
1923	Centerless infeed grinding, hand operated, hand chucking, hand removing[2]	150
1924	Centerless infeed grinding, hand operated, hand chucking, lever ejection[2]	240
1925	Centerless infeed grinding, hand operated, hand chucking, automatic ejection[2]	300
1927	Centerless infeed grinding, automatic infeed, automatic ejection[2]	450
1929	Centerless infeed grinding, hopper feed, automatic infeed, and ejection[2] (three machines operated by one man)	1,350

[1] Tolerance plus or minus 0.0005 round and straight.
[2] Tolerance plus or minus 0.00025 round and straight.

"This last operation shows another trend in machine tools. Here is one operator taking care of a multiple number of machines, which automatically perform day after day a certain operation, and the function of the operator is confined to supplying the hopper with parts, to supervising the proper functioning of machines and tools, and to checking the work as to predetermined size and finish."[1]

3. Equipment is often replaced because of the fire hazards that it involves or the danger of accident to the operator. Often, equipment is used to make the work less fatiguing to the workmen or to make dirty and disagreeable work unnecessary. This tends to reduce labor turnover.

4. It is often desirable to have motor-driven equipment replace the group drive, and some manufacturers have definitely advanced the policy of motorizing their factory. There are other important factors, such as saving in floor space, lower power consumption, and better service to customers, that deserve consideration. Directly or indirectly there is the constant desire on the part of the manager to reduce the amount of direct labor

[1] EINSTEIN, S., Machine-tool Milestones, Past and Future, *Mech. Eng.*, vol. 52, No. 11, p. 959, November, 1930.

needed. More pieces per hour may result by the use of an automatic or semiautomatic machine and it is often possible to have one operator tend several machines, which may still further reduce the direct labor cost per piece.

Formula for Computing the Savings of New Equipment.

Every new design in a machine or advance in methods is a step toward making present equipment obsolete. The manufacturer must make use of these newer economies in order to maintain an efficient factory. In some industries it is possible to use some systematic method to aid in the solution of the problems of replacing equipment. An algebraic equation can be set up which will show the comparison of the existing cost of performing an operation on a part, with the proposed or estimated cost resulting from the use of new or improved equipment.

The following formula is an example of one which gives consideration to the most important factors involved in the replacement of equipment. In this case it is desirable to know the number of years in which the new equipment, if installed, will pay for itself.

Let

X = number of years in which the equipment will pay for itself.

A = cost of the new equipment (with all necessary tools and fixtures) installed in the plant.

B = present book value, less salvage value, of the equipment which will be replaced.

C = interest charge on the new equipment at 6 per cent.

D = number of pieces to be produced per day by the new equipment.

E = present labor cost per piece (piece rate).

F = estimated labor cost per piece (estimated piece rate).

G = estimated number of working days in the year that the new equipment will be used.

H = savings (or losses, plus or minus) in operating cost, overhead, and fixed charges per year, other than interest.

Then

$$X = \frac{A + B}{(E - F)DG + H - C}.$$

Example.

At the present time there are 10 hand-operated machines performing the same operation. Ten operators have an average daily output of 250 pieces each. The rate is \$0.03 per piece. It is estimated that two automatic machines will produce 2,500 pieces per day and that two men would be required to tend these machines. The new estimated piece rate will be \$0.004 per piece. The new machines will cost \$5,200 each, installed, and the old equipment has a book value of \$9,000. It is estimated that the machines will operate 90 per cent of the time, or 270 days of the year. The estimated savings in overhead, operating cost, etc., will be \$1,500. So the data might be tabulated in the following way:

$$
\begin{aligned}
A &= 5{,}200 \times 2 = \$10{,}400.\\
B &= 900 \times 10 = 9{,}000.\\
C &= 10{,}400 \times 0.06 = 624.\\
D &= 2500.\\
E &= \$0.03.\\
F &= \$0.004.\\
G &= 300 \times 0.90 = 270.\\
H &= \$1{,}500.
\end{aligned}
$$

Then

$$X = \frac{10{,}400 + 9{,}000}{(0.03 - 0.004)\, 2{,}500 \times 270 + 1{,}500 - 624} = 1.1 \text{ years.}$$

Such a formula as this cannot be used in all industries, but in investigating the savings to be made from the installation of new equipment it is always necessary to consider all of the factors involved.[1] Many manufacturers will not replace their present equipment unless they are reasonably certain that the new installation will pay for itself within a period of from 1 to 5 years, and in a great many cases the lower figure is used.

"In a recent survey of 800 of the larger and more representative manufacturing concerns of the United States, the following question was asked: Has your company a policy against the purchase of new equipment unless the production savings will return the initial investment within a definite period? If so, what is the period?

"Nearly 200 replies were received to this questionnaire, disclosing that 43.6 per cent of the companies required that new equipment should return its cost through savings in a period of 2 years or less and that 64.1 per cent required that it should pay for itself in 3 years or less.

[1] For other formulas in use see Formulas for Computing Economies of Labor-saving Equipment, p. 90; and Formulas Used by the S. K. F. Industries, *Amer. Machinist*, vol. 62, No. 19, p. 719, May, 1925.

"Figure 11 shows the relationship between the number of years during which the initial investment must be returned and the percentage of firms requiring the return in that period or in a shorter time."[1]

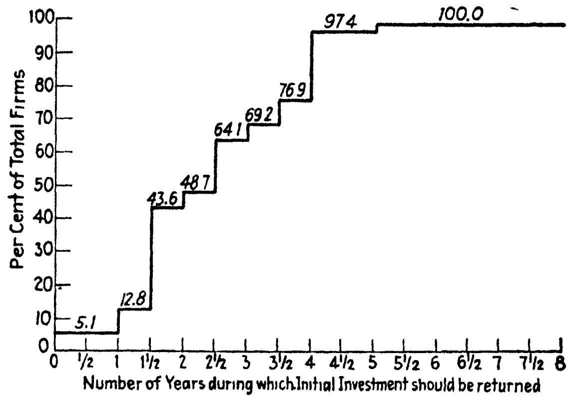


FIG. 11.—Policy of manufacturing firms in regard to the purchase of new equipment.

Standard and Special Machines and Equipment.

The manufacturer has the choice of buying standard machines or of having special ones built for his particular needs. Standard machines are, as a rule, general-purpose machines which may be used on several different kinds of work. This machine is the standard product of the machine-tool manufacturer, would have a lower first cost than special machines, and could be resold at a higher value, since it would have a wider field of use. Standard machines can be obtained on short notice, and in some cases they can be modified to fit the particular manufacturer's needs with little additional expense. When equipment is needed for quantity production of some one part, it is often found that not all of the standard attachments to the machine are needed. For example, instead of complete sets of speed and feed change gears, only one combination may be needed; or perhaps the reversing gear on the lead screw may be removed, which will bring the first cost as well as the maintenance cost to a lower figure.

[1] ALFORD, L. P., Technical Changes in Manufacturing Industries, vol. 1, p. 139, "Recent Economic Changes in the United States," Report of the Committee on Recent Economic Changes, National Bureau of Economic Research, Inc., McGraw-Hill Book Company, Inc.

Special machines may be made by the concern itself or made to order by an outside tool builder. In either case it is likely that the machine would have a high first cost. Special machines are not easily adapted to work which differs from the kind for which they are designed, and furthermore they are subjected to a greater degree of obsolescence than standard machines. Some manufacturers will not have a special machine brought into the plant unless it can be shown that it will pay for itself within a very short time, 6 months being the maximum limit in one automobile factory. Special machines are more costly to maintain and keep in repair than standard machines, from the point of view both of the actual cost of making the repairs and of the lost time while the machine is down for repair. Often a special machine, due to its great capacity, will not be kept in constant use. However, special machines can be made more nearly automatic. This reduces the direct labor cost and in other ways effects greater savings in the unit cost of manufacturing the product. The machine in some cases is a part of the process, and special equipment (often patented) is required in order to do the work at all. It is necessary and usually expected that all experimental work should have been completed and considerable certainty assured as to the continuance of the design of the product before special machines are purchased or built.

Simultaneous Operations.

"If a bar of a given diameter is to be turned up in a lathe by a single tool it is evident that the tool must travel the entire length of the bar, and the production time required might be represented by the letter T. With a tool slide designed to mount three tools equally spaced along the length of cut and all operating at the same time, the total accumulated tool time would be the same, but the production time would be represented by $T/3$." E. P. Blanchard has used the word "simultation" to describe this principle, and in the simple case just cited he would say that three is the factor of simultation.[1]

However, if the piece to be turned has two distinctly different diameters, then the cutting speed in feet per minute will not be the same for all three tools. Either it will be too fast for one and correct for the others or correct for one and too slow for the others.

[1] BLANCHARD, E. P., Economy of Integrated Production, *Mfg. Ind.*, vol. 16, No. 2, p. 121, June, 1928.

For such operations a separate machine set up for each diameter might be more efficient or, better still, a multiple-head machine similar to the one shown in Fig. 12. Figure 13 shows the relative time required to machine a gear blank using various types of machine tools such as an engine lathe, turret lathe, single-

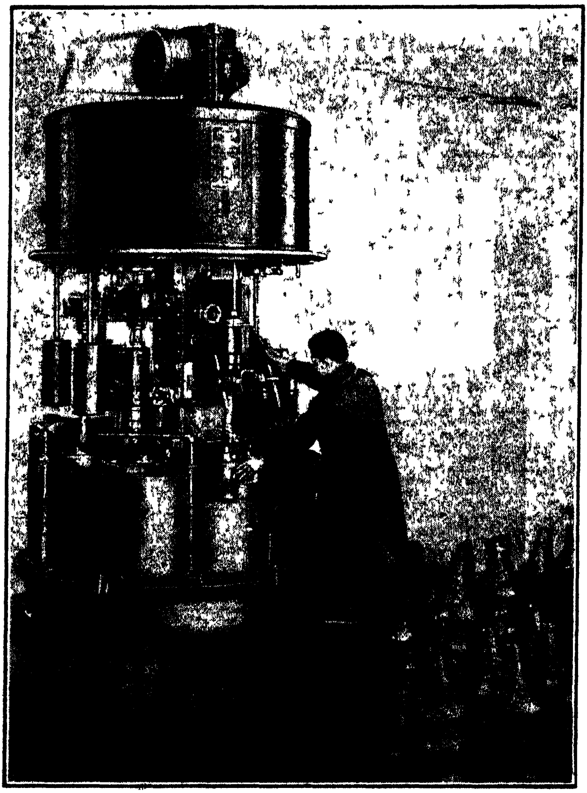
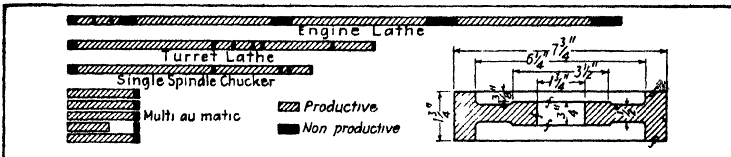


Fig. 12.—Bullard mult-au-matic. This machine performs six operations simultaneously at any desired speed and feed. In the above set-up, note the multiple spindle drill head at the sixth station which drills 14 holes in the flanges and bosses. (*Courtesy of the Bullard Machine Tool Company.*)

spindle chucker, and the mult-au-matic. The principle of simultaneous operations is applicable to a wide variety of production equipment.

Economy of Automatic Machines.

Many large industrial concerns have separate departments devoted entirely to the design and selection of manufacturing



MACHINE

ENGINE LATHE SINGLE OPERATIONS ONE AT A T ME	TIME					
OPERATIONS	PROD		NON-PROD		TOTAL	
	MIN	SEC	MIN	SEC	MIN	SEC
CHUCK				12		12
DRILL		25		2		27
BORE		24		2		26
REAM		12		2		14
PRESS ON ARBOR				12		12
MOUNT BETWEEN CENTERS				12		12
MACHINE OUTSIDE DIAMETER	3	24		30	3	54
MACHINE ONE SIDE	3	24		45	4	9
MACHINE OTHER SIDE	3	24		45	4	9
TOTALS	11	13	2	42	13	55

TURRET LATHE SINGLE OPERATIONS PLUS CROSS SL DE	TIME					
OPERATIONS	PROD		NON-PROD		TOTAL	
	MIN	SEC	MIN	SEC	MIN	SEC
CHUCK				12		2
FACE TOP AND OUTSIDE DIAM	3	24		2	3	26
DRILL HOLE		25		2		27
TRUE HOLE		24		2		26
REAM HOLE		12		2		14
UNDERCUT BORE AND UNDER'UT RIM	1	43		2	1	45
FINISH STRADDLE FACE RIM AND HUB	1	00		2	1	02
TOTALS	7	8		24	7	32

SINGLE SPINDLE CHUCKER GROUP TOOLS	T ME					
OPERATIONS	PROD		NON PROD		TOTAL	
	MIN	SEC	MIN	SEC	MIN	SEC
CHUCK				12		12
BORE HOLE AND TURN OUTSIDE DIAM	3	24		2	3	26
TRUE BORE AND STRADD E CUT RIM	1	43		2	1	45
REAM HOLE		12		2		14
STRADDLE HUB		34		2		36
TOTALS	5	53		20	6	13

MULT AU MATIC	TIME					
OPERATIONS	PROD		NON-PROD		TOTAL	
	MIN	SEC	MIN	SEC	MIN	SEC
CHUCK	1	43		8	1	51
ROUGH TURN UPPER HALF AND CHAMFER HOLE	1	43		8	1	51
ROUGH TURN LOWER HALF AND CORE DRILL	1	43		8	1	51
STRADDLE FACE HUB AND FACE RIM ON BOTH SIDES	1	43		8	1	51
FINISH STRADDLE FACE HUB AND FIN FACE RIM	1	00		8	1	08
TRUE BORE REAM HOLE AND FINISH TURN	1	43		8	1	51
TOTALS					1	51

Fig. 13.—Simultaneous operations reduce operating time

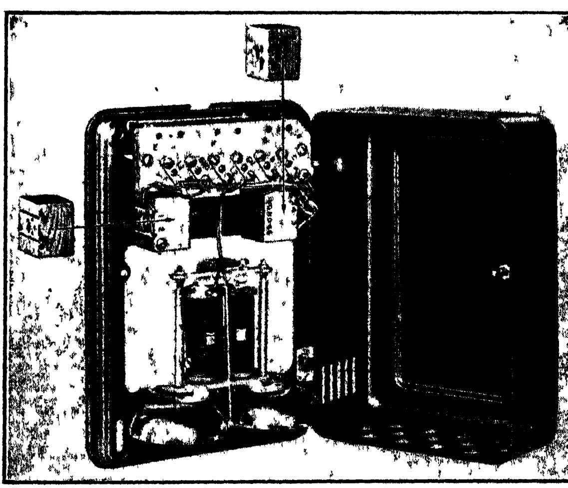


Fig. 14.—Subscriber telephone set, showing spool-head used in its construction. (*Courtesy of the Western Electric Company.*)

equipment. J. R. Shea of the Western Electric Company, Inc., gives the following analysis[1] of one of their problems:

"Manufacturing equipment recently developed for the production of a spool head used in the subscriber telephone set very well illustrates the economic factors involved. This spool head,

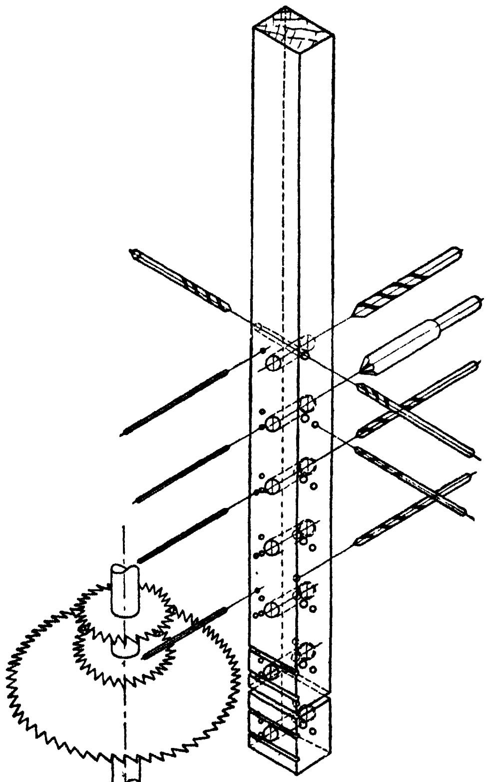


FIG. 15.—Succession of operations performed by spool-head machine. (*Courtesy of the Western Electric Company.*)

shown in Fig. 14, is approximately 1⅜ in. square and 1 in. thick and is made of maple. Several millions of these parts are required per year, and they were formerly made by the operations which are listed in Table II, standard woodworking machinery being used.

[1] SHEA, J. R., Outstanding Economic and Technical Factors Involved in the Engineering of New Manufacturing Equipment, *Trans. A.S.M.E.*, MAN.-51-7, p. 49, January–April, 1929.

"A study of the design of the subscriber set in which this part is used and of the various materials from which the spool head

TABLE II.—OPERATIONS AND EQUIPMENT USED IN MANUFACTURING SPOOL HEADS BY OLD AND NEW METHODS

Operation	Old method	New method
1. Trim to $1\frac{3}{8}$ in. and cut two slots	Trim saw	Parts cut, slotted, and drilled complete in automatic machine
2. Drill $\frac{1}{2}$-in. core hole in heads	Speed lathe	
3. Drill eight holes in head	Adjustable multiple-spindle drill press	

could be made indicated that maple would still be the best and cheapest material available. We investigated the best standard machines on the market which were adaptable to the production of this part but were unable to find an improved type with which any appreciable saving could be realized. The operations required to produce this part are essentially drilling and sawing, and our engineers considered it entirely feasible to develop a special machine in which all the operations could be combined. The operations performed by this special machine are shown schematically in Fig. 15, and the machine itself in Figs. 16 and 17, while Table III is a comparative economic statement of the old and new methods of producing this part.

TABLE III.—COMPARATIVE COSTS OF MANUFACTURING SPOOL HEADS BY OLD AND NEW METHODS

Investment	Old method	New method
1. Machine investment	\$10,000	\$15,000
2. Building investment	\$ 3,200	\$ 1,000
3. Raw and process material	\$ 1,500	\$ 1,000
4. Total investment	\$14,700	\$17,000
Annual costs		
5. Annual labor cost	\$21,000	\$ 2,600
6. Total annual cost	\$54,000	\$ 7,200
7. Total annual saving	....	\$46,800
8. Number of operators required	10	1

"There are a number of design features embodied in this machine which are unique and which make possible to a large

extent the savings that have been effected. The drilling speed used is 8,000 r.p.m., while the speed obtainable with the best commercial multiple-spindle drill press of the required capacity does not exceed 3,000 r.p.m. This high speed was obtained by the use of direct-motor drives with a frequency changer, which made it possible to increase the speed of standard motors with-

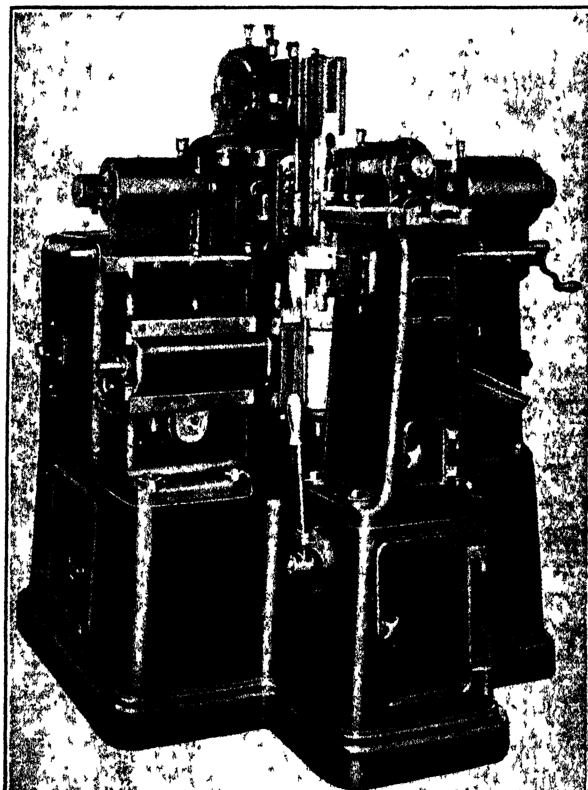


FIG. 16.—Semi-automatic spool-head machine (*Courtesy of the Western Electric Company.*)

out resorting to special design. Ball bearings were used throughout, and a splash lubrication system was adopted. A special feature of the multiple-saw mechanism of this machine is that the motor housing is made of an aluminum alloy to cut down its weight, so that both the motor and saws may be moved to and from the work with great rapidity. The saw motor runs at 7,200 r.p.m., a saw speed that is unusual in the woodworking

industry. This high speed was adopted in order to make it possible to use small saw diameters, thus insuring greater accuracy, and yet keep the time required by the slotting and sawing operation at a minimum, since that is the operation which limits the output. The present output of this machine is 25 parts per minute."

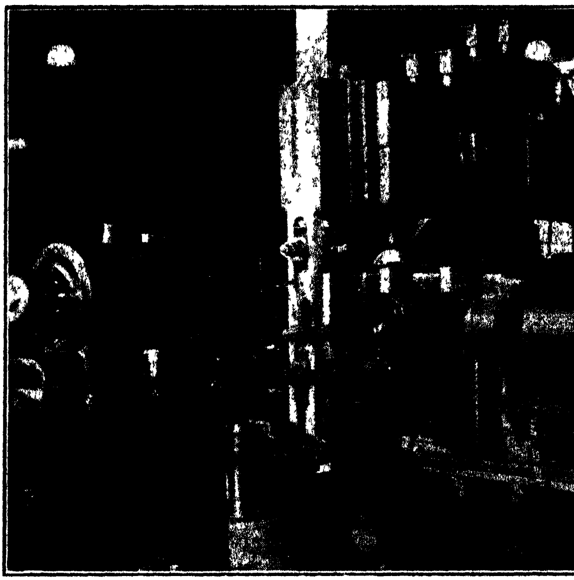


FIG. 17.—Arrangement of drill and saw units of spool-head machine. (*Courtesy of the Western Electric Company.*)

Factors Affecting the Selection of New Equipment.

In selecting any type of equipment some or all of the following factors will require consideration:

1. The extent of the use of the machine. Is it a special tool or can it be used on a wide range of work?

2. Length of life. How rapidly will it depreciate?

3. Kind and size of bearings and provision for lubrication. How many ball or roller bearings are used, are they of adequate size? Has the machine a central oiling system? Are there any bearings improperly provided with lubricating devices?

4. Power consumption. Will the machine throw added load on the power plant? What is the nature of the drive—individual motor, single pulley, or cones for belt drive? Will it require a steady supply of power or is it intermittent in its power demand?

5. Rigidity and strength of the members. Will the machine stand up under heavy loads? Will vibration and chatter make the equipment undesirable for the class of work that it must perform?

6. Fire hazards. Is the equipment satisfactory in this respect? Will it affect the fire insurance rates?

7. Safety and industrial codes. Is the machine safe for the operator? Will it be easily damaged by inexperienced or negligent operators? Is it "fool proof"? Will the equipment satisfy all state or city industrial codes and requirements?

8. Accuracy. Is the machine capable of giving continued service with the same accuracy as when new?

9. Capacity of output. Will the machine give the desired output? Will it mean an over-equipping of the shop in that it will have to remain idle a considerable length of time each week or month?

10. Cost. How does it compare with other equipment in the field as to first cost? How will the cost of the accessories and tools compare with those now in use? What will the repair bill be for the year? How costly will the installation be and how long will it take? Will it disturb the present equipment? Will crane service be needed? What provision will be required for compressed air, steam, hot or cold water, special voltage, alternating or direct current? What will the coolant cost?

11. Floor space. What floor space will be required not only for the machine itself but for the accessories, overhang of the table or spindle, space for material, and the working space for the operator? Is the machine automatic, semiautomatic, or hand controlled? How conveniently are the controls arranged?

12. Labor. Will the machine require skilled, unskilled, or semiskilled workmen? Can one workman operate several machines? Will the work be dirty, fatiguing, or noisy? Will the operator be subjected to constant vibration due to the machine?[1]

AMOUNT OF EQUIPMENT REQUIRED

After the kind of equipment has been selected it is a much simpler matter to determine the amount that will be required to

[1] For a further discussion see M. S. Curtis, The Economics of Machine-tool Replacement, *Mech. Eng.*, vol. 49, No. 9, p. 966, September, 1927. Also, L. C. Morrow, Shop Equipment Policies in Representative Plants, *Mech. Eng.*, vol. 49, No. 9, p. 970, September, 1927.

give the production desired. Of course, it is difficult to estimate the quantity of goods to be manufactured, but assuming that this is known, then the factors to be considered in estimating the amount of equipment required would be as follows:

1. The length of the working day and the number of shifts per 24 hr. is fairly well standardized for a particular industry.
2. The capacity of the equipment in units per hour can be estimated very closely. Manufacturers of new equipment will supply these data, or time studies can be made for this purpose. Allowances must be made for set-up and preparation time.
3. A certain amount of time is required for maintenance and repairs on all equipment. Besides, it cannot be assumed that the shop will operate at 100 per cent efficiency. The average is more likely to be 80 to 90 per cent.
4. The amount of equipment required will also vary with the type of industry and the arrangement of the machines in the shop.

Determination of Economic Lot Sizes.

In a jobbing shop or in an industry of the intermittent type, the set-up or preparation time of the machine becomes an important factor not only in the calculation of the amount of equipment required but also in the economical operation of the factory. Figure 18 shows how the set-up cost and the number of pieces processed at one set-up affect each other. The determination of the point of greatest economy in manufacturing lot sizes will involve (1) the total capital invested, (2) the preparation and set-up costs, (3) storage costs, (4) deterioration and obsolescence of the manufactured parts as well as the raw material, (5) the total manufacturing costs, (6) possible rate of production, *i.e.*, yearly capacity of the plant, (7) sales demand, (8) rate of interest, (9) reserve held in stores for emergency purposes, and other factors.

Considerable study has been directed toward the development of a mathematical equation which would make possible the accurate determination of economic lot sizes. It is entirely possible to set up formulas that will include all of the factors that could possibly enter into the problem. When this is done, however, the equation becomes rather involved and is likely to be objected to because of its complexity. For many uses a simpler formula may be substituted for the more complex one, since some factors may be of such minor importance as to be dropped without appreciably decreasing the value of the formula.

Professor F. E. Raymond has analyzed this problem very thoroughly and the results of his research are included in Appendix B.[1]

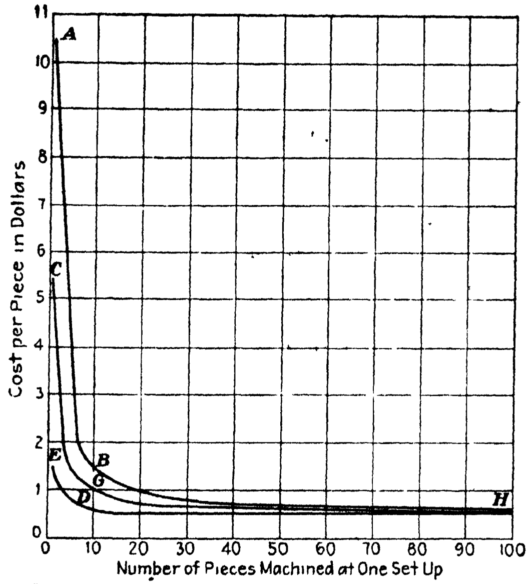


FIG. 18.—Curves showing the effect of set-up cost on unit cost of piece.

The data for the curves in Fig. 18 are given below.

TABLE IV

Number of pieces made per set-up	Set-up	Curve *EDH* when the set-up cost is $1		Curve *CGH* when the set-up cost is $5		Curve *ABH* when the set-up cost is $10	
		Total cost	Cost per piece	Total cost	Cost per piece	Total cost	Cost per piece
1	1 × 0.50 + set up	1.50	1.50	5.50	5.50	10.50	10.50
10	10 × 0.50 + set-up	6.00	0.60	10.00	1.00	15.00	1.50
20	20 × 0.50 + set up	11.00	0.55	15.00	0.75	20.00	1.00
30	30 × 0.50 + set up	16.00	0.533	20.00	0.67	25.00	0.83
40	40 × 0.50 + set up	21.00	0.525	25.00	0.62	30.00	0.75
50	50 × 0.50 + set up	26.00	0.52	30.00	0.60	35.00	0.70
100	100 × 0.50 + set up	51.00	0.51	55.00	0.55	60.00	0.60

[1] For a complete discussion of this subject see F. E. Raymond, "Quantity and Economy in Manufacture," McGraw-Hill Book Company, Inc., 1931.

Amount of Equipment Required, Sample Problem.

Problem.—Determine the amount of equipment required for the manufacture of 4,000 flywheel clutches per month of 25 working days. Assume an 8-hr. day and a shop efficiency of 90 per cent.

Because of the technical knowledge required, no attempt will be made to determine the kind of equipment required for the manufacture of the flywheel clutch. This part of the problem will be solved by taking the equipment that is now used by one of the large manufacturing concerns in this country. With the information at hand it then becomes the problem to determine the proper amount of equipment that will be needed to manufacture 4,000 clutches per month (see Appendix A). After the amount of equipment has been determined, another problem will deal with the layout and arrangement of this equipment in the factory in order to bring about the greatest efficiency possible.

The methods of manufacturing each part have been listed on the operation sheets in Appendix A, and the standard time required by each machine for each operation is indicated. It is therefore necessary to find the total time that each machine will be in operation and then divide this total by the number of hours that the factory will operate per month. The quotient will be the number of machines that will be needed to manufacture the 4,000 clutches per month. The form shown in Fig. 19 is a convenient way in which to collect this information. In the first column of this form is listed the number of the part, in the second the name of the part, and in the third the number of pieces that will be required per clutch. The fourth column shows the number of pieces that should be made per set-up of the machine. If the continuous method of manufacture were used, then the item of set-up might be neglected; but since different kinds of clutches will be made, it becomes necessary to use the same machine for different kinds of work. For instance, the duplex automatic drill is used for "milling the lugs" (operation 1 on the clutch shifter collar, part C105), and also this same machine is used for "milling the flat on the flange" (operation 4 on the front bearing retainer for the transmission shaft, part C116). It is therefore necessary to set up the machine and process a number of the shifter collars and then tear down the set-up and set up the machine for milling the

Part number	Part name	Number of pieces per assembly	Number of pieces per set-up	M1 Duplex automatic mill	L2 Chucking lathe P & J	M3 Vertical boring mill	A4 Automatic cut-off machine	A5 Automatic screw machine	D6 Automatic drill	A7 Gridley automatic	A8 Automatic screw machine	L9 Automatic lathe	D10 Heavy-duty drill	D11 Special multiple drill	D12 Nacto-multiple drill	D13 Multiple drill—16 spindle	D14 Bickford drill	D15 Radial drill	D16 Avey sensitive drill	D17 Allen sensitive drill	D18 Avey sensitive drill No. 3	L19 Warner & Swasey turret lathe	L20 Warner & Swasey No. 3A	L21 J & L & turret lathe	L22 Turret lathe—W & S
C101	Spacer for clutch hub......	1																							
C102	Release collar for clutch	1																							
C103	Pin for clutch-release collar ..	1																							
C104	Clutch-shifter collar assembly	1																							
C105	Clutch-shifter collar..........	2																							
C106	Lock for clutch drive pin . .	4																							
C107	Pin for clutch-release link....	8																							
C108	Pin for clutch-release cam.....	4																							
C109	Clutch drive-link spacer.......	4																							
C110	Pin for clutch drive link ...	4																							
C111	Clutch adjusting collar.. .	1																							
C112	Clutch pressure plate	1																							
C113	Transmission shaft....... ..	1																							
C114	Clutch driving plate..........	1																							
C115	Clutch driven plate	1																							
C116	Front bearing retainer for transmission shaft....	1																							
C117	Clutch-release link...........	8																							
C118	Release cam................	4																							
C119	Clutch hub..................	1																							
C120	Pressure-plate assembly (made up of 3 parts)...............	1																							
C121	Clutch drive pin...........	4																							
C122	Driven-plate assembly (made up of 3 parts)	1																							
F123	Flywheel bolt....	6																							
S124	Crankshaft timing-gear key	1																							
S125	Crankshaft timing gear.......	1																							
S126	Crankshaft............ ..	1																							
F127	Flywheel....................	1																							
	Total number of hours required																								
	Total number of machines required............																								
	Actual number of machines to be purchased..............																								

Fig. 19.—Form used in calculating

flat on the flange, etc. There are many factors involved in the determination of the number of pieces that should be machined at one set-up, as has already been explained. For this part of the problem the number of pieces that will be machined at one set-up is indicated in the fourth column of Fig. 19. In the following vertical columns of the chart are indicated the name

S23 Newton cut-off saw	D24 Allen sensitive drill	D25 Bickford tapping drill	D26 Avey 2 spindle drill	G27 Norton cylindrical grinder	G28 Norton grinder 20 by 96 in.	G29 Norton crank grinder	G30 Blanchard surface grinder	H31 Barber Colman hobber	T32 Bradley trip-hammer	B33 LaPointe No. 3 Borach	B34 LaPointe No 4 Borach	L35 Centering lathe	L36 Le Blond engine lathe	L37 American engine lathe	L38 Le Blond engine lathe 17″	L39 Le Blond engine lathe 19″	L40 American lathe 24″	L41 Hand-screw machine	L42 Hand-screw machine No 4	L43 Lo-Swing special lathe	L44 Crank shaft lathe	M45 Whitney hand mill	M46 B & S plain mill	M47 Cincinnati horizontal mill	M48 Cincinnati horizontal mill No 4	M49 Key seat mill	M50 Milwaukee horizontal mill	P51 50-ton hydraulic press	P52 Double punch press	P53 Power shears	H54 Fellows gear shaper	P55 Inclined punch press	X56 Bench		Part number
																																			C101
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the amount of equipment required.

of all machines that will be needed in order to perform all of the operations on the clutch, flywheel, crankshaft, and the timing gear.

CHAPTER III

PLANT LAYOUT

Buildings, machines, tools, in fact the whole physical equipment of a manufacturing plant, are the instruments used to produce the finished product. It is the processes and methods of manufacture that determine the layout of the factory. Once the building is erected and the machines and the departments are located it becomes a costly task to undertake wholesale alterations and changes. In order to have the most economical factory arrangement, the flow of work should take the shortest route from one machine to the next. To attempt a plant layout intelligently requires a thorough knowledge of the details of the processes and methods of manufacture, as well as the kind of material to be used and the sequence of the operations to be performed upon the material.

If a new factory is to be built, it is a much simpler task to make an efficient and practical layout of the machines and departments than is the case where an old plant or department is to be rearranged. However, even in a new plant a permanent layout can never be attained, because new processes, materials, and methods are constantly being found which call for rearrangements.

Types of Industries.

A plant may "build" its product or "manufacture" it. A large steam turbine, some heavy machine tools, expensive foreign cars are built, not manufactured. The parts for such products are machined as individual jobs and are, perhaps, fitted together by hand in assembly. The work of some small jobbing shops would consist of building, since the quantity to be made would be small and there would probably never be a repeat order.

Quantity output and mass-production methods form the basis for much of the manufacturing in this country today. Proper limits and tolerances are maintained, making all parts inter-

changeable. This idea of interchangeable parts probably originated in Europe, but its adoption by American industry proved to be a great forward step, particularly in the manufacture of large quantities of standard parts.

Manufacturing may be carried on by either the continuous method or the intermittent method (sometimes called assembly or jobbing type). In the continuous process the machines and production centers are located in such a way that the raw material might be received into one end of the factory and pass directly through the plant, being finished and shipped without any retracing or delay. Sugar or petroleum refineries, wire mills, flour mills, and by-product plants are good examples of industries using this method of manufacture.

Continuous industries may be either synthetic or analytical. An analytical industry is one in which the raw material goes through a series of operations and processes resulting in several finished products. Crude oil is refined into gasoline, kerosene, benzine, and other products. Corn is converted into starch, oil, and syrup.

Synthetic industries are those in which several raw materials are used to make one finished product, as the manufacture of window glass, paper, rayon, and portland cement.

In the intermittent method the raw material may be worked into partly finished goods and then stored, later to be withdrawn as needed and finished for assembly. Sometimes the parts are finished and subassemblies made and then these are stored until they are to be used to make up the finished product. Typewriters, automobiles, washing machines, and other products of similar nature lend themselves to this method of manufacture.

The above classification will aid in analyzing the problem of plant layout and may make it possible to formulate some general rules that can be applied to the industries falling into the different classes.

The Major Factors of Plant Layout.

The problem of laying out and equipping a factory is a many-sided one, since there are so many elements that must be given consideration. The following factors seem to be of major importance in practically every layout:

1. Methods of arranging equipment.
2. Determination of production centers.

3. Methods of applying power to the machines.
4. Location and coördination of departments.
5. Arrangement of service centers.
6. The application of direct-line layout.
7. Provision for adequate internal and external factory transportation.
8. Provision for future expansion and growth.
9. Consideration for safety and fire protection, city and state factory codes and laws.
10. Provision for proper lighting, heating, and ventilation.

Methods of Arranging Plant Equipment.

There are two methods commonly used in grouping machines in the factory. First, the machines may be arranged according to their kind. Thus, all machines performing the same kind of work, such as drilling, might be placed in one department. All of the milling machines might be grouped together in another department, and so on.

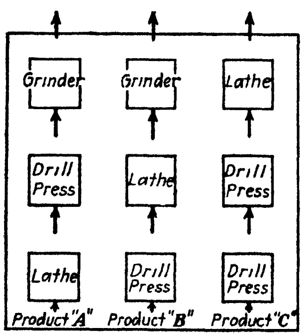


FIG. 20.

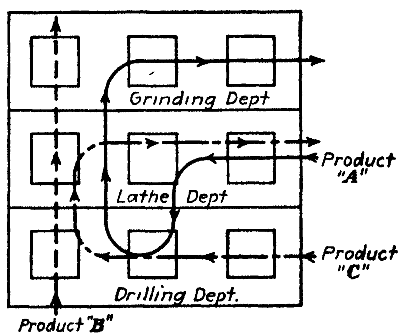


FIG. 21.

FIG. 20.—Machines arranged according to the sequence of the operations to be performed. Each department manufacturers one product.

FIG. 21.—Machines arranged according to kind, a department for each type of machine.

The second method is that of laying out the machines according to the sequence of the operations to be performed or according to the similarity of the parts to be manufactured. The layout of the department in this way will permit the work to flow in as direct a line as possible and this department will contain all of the equipment necessary to manufacture the finished part or parts completely.

Each of the two methods of layout has its particular merits. The first method gives greater latitude in the variety of parts to be made, makes supervision easier, and aids in the specialization of operators and of departmental repair men as well as foremen. By having all of the machines of a kind together in one department there is the increased possibility of keeping all of the machines in operation. This method also results in a lower investment in equipment, since there is no need for duplication as might be the case in the straight-line layout where the same type of machine would be required at more than one place in the line on different operations. It is possible that the machine would not be used to its capacity in either place.

It is, however, often desirable to place in one department all of the specialized machines, such as automatic screw machines and lathes, gear hobbers, hardening and heat-treating equipment, nickel-plating apparatus, and the like.

When machines are grouped according to kind, there will be more material in process, which means that the parts will accumulate after each operation, thus requiring more floor space around each machine and perhaps demanding special provision for storage between operations. The length of time from the first operation to the assembly department will be the total time of all operations, times the number of pieces in each lot. Since most machines require special set-ups for the different operations on different parts, it is economical to have a considerable number of parts in a lot or batch. By arranging the machines in line instead of grouping them as to kind, it may take only a few hours for the parts to flow from the first operation to the last, while in the other method of layout it may be a week or so before the lot has passed through all of the different operations. Of course, by keeping the lot sizes small, the total time as well as the amount of material in process could be decreased. This would, however, be offset by the increased cost of set-up, handling, inspection, etc.

The second method of machine grouping reduces the handling cost and lessens the confusion due to such handling. It lends itself well to the use of gravity conveyors and reduces moves to the shortest possible distance. This method might be used to good advantage where the machines are specialized or in the continuous type of industry where operations are grouped according to the character of the finished product. There may

be an advantage in manufacturing the product complete in one department, in that there will be no complications with other departments; also better control of output as to both quality and quantity may result. If machines are properly balanced as to their output capacity, much less attention would need be given to production control. There is also the possibility of an interruption on one machine, due to breakdown or hold-up in the work, affecting the flow of work on the following machines in the line. It is also more difficult to provide for expansion of the plant, especially where permanent conveyors and other equipment have been installed. Some manufacturers making several lines of products may arrange the machines in direct line to manufacture the main parts of the product and then group the machines which make the minor parts.

In arranging the machines according to the sequence of the operations in a direct-line layout, it has been inferred that there might be one machine of a kind followed by one of another, but in many cases one machine does not have sufficient capacity to do the amount of work required; then two or more would be used and the parts would flow from one group of machines to another.

In assembly or intermittent industries where relatively small quantities of many different parts are made, it is likely that the first method of grouping would necessarily be used; while in the continuous industries and where special machines and equipment are necessary, the second method of grouping would find extended use.

It is sometimes more desirable to have several small departments containing the same kind and type of equipment than one very large department for all of this equipment. This makes it possible to locate the several small departments so that "back tracking" is reduced to a minimum.

Automatic Frame Plant.

The A. O. Smith Corporation operates an automatic assembly plant in Milwaukee capable of assembling 10,000 automobile frames per day. Figure 22 shows the straight-line layout.

"There are 10 lines or production units, operating in synchronism. Broadly speaking, the whole plant is geared to a single rate of output, so that the same impulse which takes in a set of strip steel blanks at the receiving end of the line may be said to deliver a finished frame at the shipping platform . . .

"Dividing the plant in 10 units also provides a necessary flexibility, in case of interruption of one line. Otherwise the whole plant would have to stop if a single operation jammed.

"The first of the 10 units receives the raw material and automatically inspects, cleans, pickles, and oils the steel strips. This unit operates on the ordinary continuous-flow principle but at the same proportionate speed as the reciprocating lines. It delivers the steel to the second unit, or press line, which offsets, pierces, blanks, and forms the side bars, both right and left hand. This whole line of presses is driven by a single 500-hp. motor. The side-bar blanks are advanced from one press to the next by a series of reciprocating rails with feeding dogs. These dogs push the piece in steps, from the bed of one press on to centering dowels in the next, turning over every other bar in order to make right and lefts.

"The third unit completes the side bars and assembles the various small brackets and fittings required. The next four units form complete the four cross-members of the frame including the front and rear engine brackets.

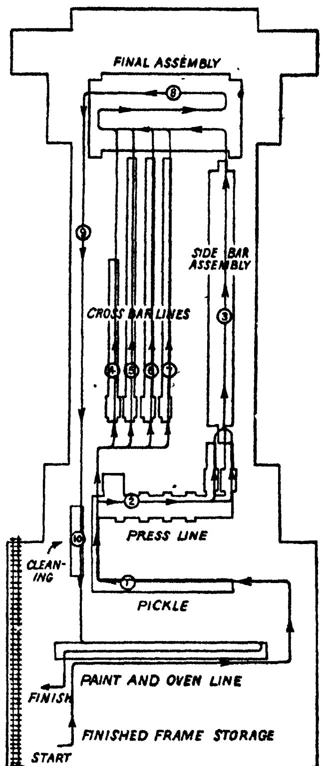


FIG. 22.—Layout of the automatic frame plant. (*Courtesy of the A. O. Smith Corporation.*)

"These four lines and the side-bar assembly line run parallel to the length of the shop and meet the eighth unit, the general assembly line, at right angles, as shown in Fig. 24. These five lines all operate on the reciprocating principle, the same as the first unit. Each of the crossbar lines is driven by a single motor of 100 hp. The side-bar line requires 200 hp.

"Final inspection and repair are handled by the ninth unit, while the tenth is enameling and baking, which is done in the usual way on a continuous conveyor.

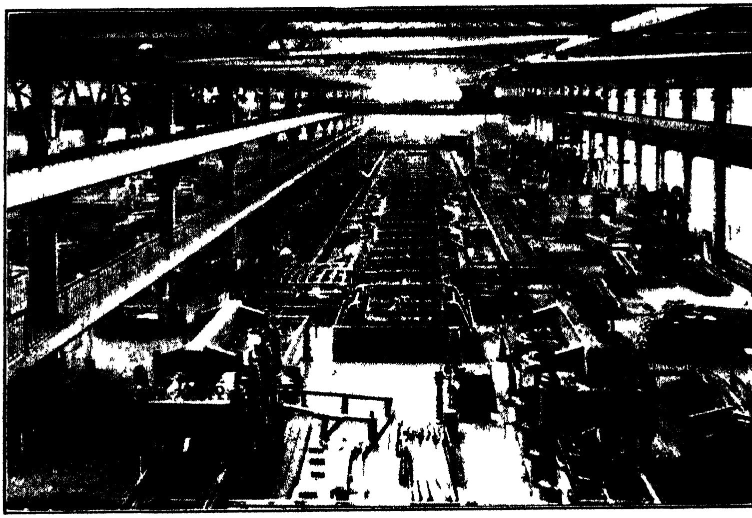


Fig. 23.—Automobile frame plant side-bar parts assembly line. Forming presses are in the foreground. This plant not only has been laid out for straight-line production but it is also automatic in its operation. (*Courtesy of the A. O. Smith Corporation.*)

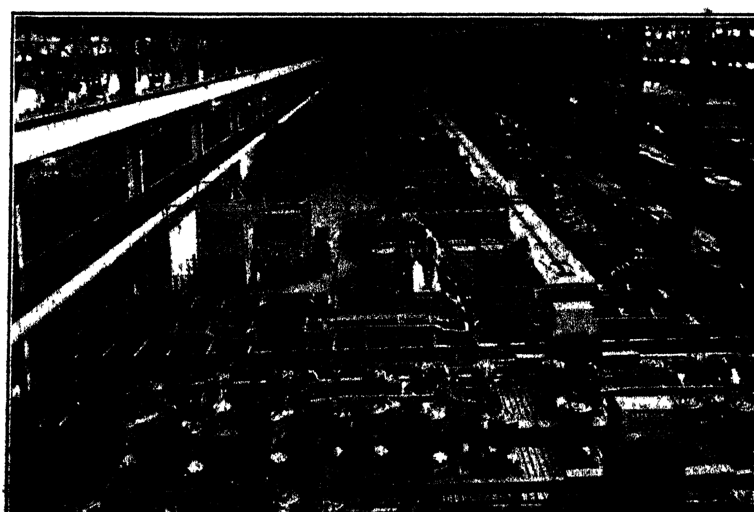


Fig. 24.—Part of the final assembly line of the automobile frame plant. (*Courtesy of the A. O. Smith Corporation.*)

"A description of the side-bar assembly line will illustrate the method employed in all the other lines. This line is equipped with 38 carriages, linked in a chain which passes through 18 working positions and returns empty. On each side of the line, and parallel to it, is a pair of long racks—heavy bars provided with gear teeth—which serve to transmit the power simultaneously to as many as 100 riveting machines, shears, and other tools placed along the line. . . .

"A few of the operations on this side-bar line, such as placing rivets, are performed by hand. On the final assembly line, however, even this work is automatic. A machine was developed which picks up each part of the frame separately, brings these parts into alignment, and holds them there while 60 or more rivets of various sizes are shot into the rivet holes by compressed air. In a few seconds all of the rivets are in place, then this same machine again picks up the frame and puts it on a truck.

"This truck is one of an endless chain which moves through 13 more stations, at the last of which the completed frame is stripped off . . .

"The cost of a change-over, when a new order is to be run, is a vital question. When we come to the end of a run, the plant is shut down from 6½ to 12 hr., while a force of 200 mechanics change dies and reset tools. The cost of a set-up does not justify making runs of less than 10,000 frames, and every effort is made to secure longer runs."[1]

It might be added that it took 5 years and $8,000,000 to build the automatic plant as described above. "Ten times the plant was built on paper at a cost of $1,500,000 for pencil roughs," states L. R. Smith, president of this company.

Production Center.

The amount of floor space actually occupied by the machine does not give sufficient information for the layout. In addition to providing space for the machine itself, it is necessary to have room for the material in process, which must be placed conveniently for moving the pieces both to and from the machine. The operator must have sufficient working room and space must be provided to get the material to and from each machine. Furthermore, tool racks and auxiliary equipment are often needed.

[1] REDLIN, A. W., Automatic Assembly, *Factory and Ind. Management*, vol. 77, No. 1, p. 48, January, 1929.

Individual motors may be built into each machine or they may be placed on the floor near the machine, and when this is the case extra space must be provided.

When belting is used to drive the machine from overhead shafting or from a shaft placed on the floor, special consideration is required. The machine may be very heavy or because of its intermittent action it may set up an unusual amount of vibration, necessitating special foundations. The work place, including the machine and its necessary equipment is called a production center.

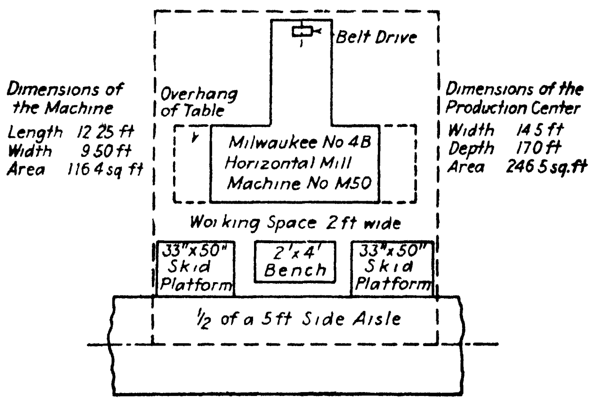


FIG. 25.—Layout of a production center for a horizontal milling machine.

Figure 25 shows the layout of a Milwaukee horizontal milling machine. This production center includes space for the machine as well as that required for the overhang of the table. Skid platforms are used for incoming and outgoing work in process. A bench with a heavy wood top and two cast-iron shelves provides space for the auxiliary tools and equipment that may be needed at the machine. Half of the side aisle as well as working space for the operator is considered as a part of the production center. The machine itself occupies only 116.4 sq. ft. of floor space, while the production center requires 246.5 sq. ft. This last figure is the one that is used in laying out the space for this machine.

Methods of Supplying Power to the Machines within the Plant.

The old idea of having a single motor or engine furnish power to the entire plant has given way to the more modern methods. Today power may be supplied to the machines in either of two

distinct ways, and in any shop it is likely that both of these methods will find their uses. (1) An individual motor can be used to drive each machine; or (2) several machines may be grouped together, these being driven by belts connected to a jack shaft which is driven by a single motor. In this manner all of the machines in one department might be driven by one motor.

Many machine builders have designed their machines with the built-in motors transmitting the power to the machines by (1) belt, (2) gearing, (3) silent chain, and in some cases with the (4) motor direct connected to the spindle or shaft carrying the cutting tool. More than one motor is often used on a single machine and this frequently simplifies problems in machine design, especially when the machine spindles are not parallel to each other and where it is necessary constantly to vary the angle either in operating the machine or in setting it up. Motors and starters are now built in very compact form and it is possible to have the complete unit contained within the machine itself. It is simply a matter of disconnecting the wiring when it becomes necessary to move the machine to some other location in the shop. It seems that the individual drive has its widest use for woodworking machinery, high-speed drills, and grinding machines of all kinds.

There are a number of factors which favor the group drive and in many cases the initial cost of the group drive installed is very much less than individual motor drive for each machine. There are several reasons for this. With individual motor drive the motor must be of sufficient capacity to carry the maximum load that the machine will ever require. Assuming that eight machines of similar kind are grouped together and that all are connected to a common shaft driven by one motor, it is safe to say that this motor need be only 20 to 30 per cent as large in capacity as the sum of eight individual motors driving these machines. This is true because it is not at all unusual to find a machine running idle one-quarter to one-half of the time while work is being placed in the machine, inspected, gaged, or removed from the machine. The peak load on each of these eight machines would not be likely ever to come at the same time. Besides, one or two of the machines might be idle a large part of the time due to lack of work or to being down for repairs or set up, and even if the motor is overloaded for a short period it will not heat up enough to injure the windings.

FIG. 26—Belt-driven hand-screw machine department (*Courtesy of the Western Electric Company.*)

FIG. 27.—Motorized hand-screw machine department. (*Courtesy of the Western Electric Company.*)

It is apparent that the group drive has the advantage from the point of initial cost and in many cases it is the most economical to operate. The maintenance cost of a 40-hp. motor, for example, is very little greater than that of a 2- or 3-hp. motor. Of course the repairs will cost more for the large motor but this is less than one-quarter of the maintenance cost, labor being the greatest factor involved. It takes almost as long to inspect a small motor with its starter as it does a large one, and so in the above example this would favor the group drive eight to one. Installation costs as well as power consumption adds to the desirability of using the group drive.

Since the ordinary induction motor requires about as much magnetizing current at light loads as at full load, it is apparent that the power factor of a plant using a great number of small motors running at from one-quarter to one-half full load or less will likely be low, and that means a higher power cost. It is not at all impossible to have a motor on group drive average 85 to 90 per cent of its full load; half to one-third of this figure would be considered very good average performance for individual motors. In some plants the low power factors become so serious that some definite steps must be taken to remedy the condition. When possible, all motors should be carefully selected so that each machine will have the correct size of motor for the work to be done by the machine which it drives. This is often a much smaller motor than the one supplied as standard equipment by the manufacturer of the machine. Where large power units can be used and where low speeds are needed, it is possible to use synchronous motors which will help correct a low power factor.

The individual motor drive is a very flexible arrangement, and where machines are carrying a heavy continuous load or use power intermittently, it is likely that this drive would be most economical. Of course individual motors are used on all portable machines as well as on machines which are used by the maintenance department and those commonly used during overtime or odd shifts. The individual motor drive eliminates the hazard of breaking belts, and in some shops dripping oil and dust and dirt from overhead pulleys are very undesirable. With a motor for each machine the cost and maintenance of the overhead shafting are eliminated, but where gear or silent chain drive is used in connecting the motor to the machine the motor is sub-

jected to the sudden jerking of the machine which is smoothed out by a longer leather belt. The inertia of belting, shafts, and the other machines of the group also help to absorb and even out the sudden pulls that would take place intermittently.

The individual motor drive makes possible the elimination of the mass of overhead belting, shafting, pulleys, and shifting levers which impair the natural and artificial lighting and distract from the general appearance of the shop. In general, the present tendency is toward the greater use of individual drive rather than group drive.

Location and Coordination of Departments.

Knowing the number of each kind of machine and each unit of equipment needed, and having decided upon the arrangement of the machines, the next point to be considered is the location of the departments. If a multistory building is to be used and the industry falls into the continuous type, it might be well to store the raw materials on the top floor and have the general flow of work from the top to the bottom of the building. In this event the manufacturing or processing departments would be located according to their natural sequence. Exceptions to this rule would be made where parts are heavy, bulky, fragile, or require operations of a hazardous nature. The transportation of bar stock or heavy castings can be minimized by placing the departments using such material near the receiving and storage departments, while at the same time it might be more economical to store and machine the small parts on upper floors. Equipment and processes involving dust and objectionable fumes and gases are usually separated from the rest of the plant by partitions, and operations that are hazardous or especially noisy may be placed in separate buildings. The testing departments may need to be free from noise and vibration, and when this is the case special thought must be given to the location of such departments.

In locating the shipping and receiving departments, consideration must be given to the relative positions of the other departments of the plant as well as the location of the railroad sidings, industrial railroads, driveways, and raw- and finished-material storage spaces. It is often found that these two departments can be conveniently located near each other, often side by side.

Adequate provision must be made for the storage of raw material and finished products. These storage spaces may be adjacent

to the receiving and shipping departments, or perhaps all of these departments could be grouped together, in the small factory.

Foremen's and superintendents' offices are located after the departments have been laid out. Whenever possible it is desirable to group several offices together. Often there are advantages in having these offices totally enclosed or at least partitioned off with portable partitions. The general offices are located centrally with respect to the factory proper and

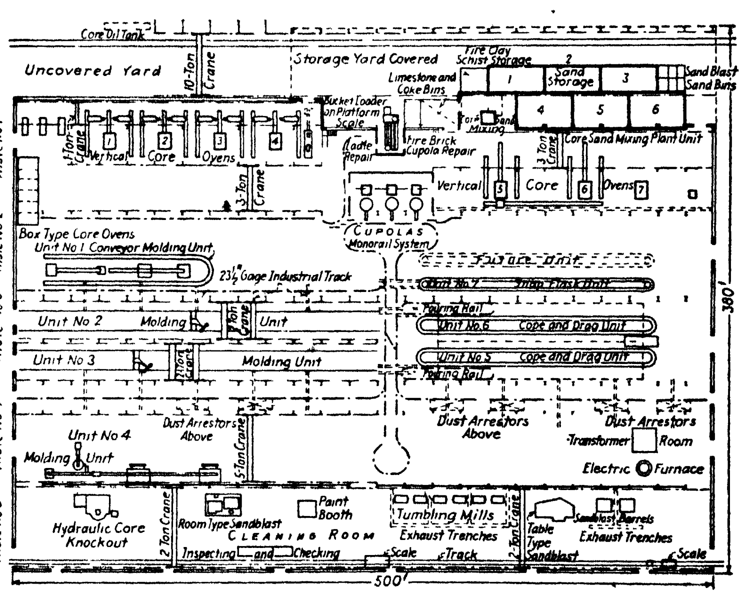


FIG. 28.—General layout of the foundry showing the relative position of the various departments, Caterpillar Tractor Company. (*Courtesy of the Foundry.*)

are convenient to the outside entrance or to the main passenger elevators.

It is the policy in some plants to have a number of small departments with few supervisors rather than a large department with more supervision. In either case, consideration must be given to the balance of the different departments and operations. By balance of departments is meant the equalizing of their capacities per unit of finished product made. It is not at all unusual to find one department in a factory equipped to turn out twice as much as another department. It may be, for example, the heat-treating department or the final-assembly

department that is the "bottle neck." This so-called "key" department determines the maximum number of finished units of the product that can be produced per day. It is a waste of capital to have this unbalance in capacities of departments.

In the design of the automatic frame plant of the A. O. Smith Corporation, the very greatest care was exercised to see that all parts are manufactured and supplied to the final assembly line as they are needed. A. W. Redlin, assistant works manager for this company, explains:

"The average automobile frame is composed of 125 parts, and 500 to 600 operations are required to produce the finished frame. The automatic plant alone turns out 10,000 such frames every 24 hr., and accordingly the machinery is performing some 5,000,000 operations in a day's production. It is indeed a sizable figure, and it means something when one considers that every one of the operations must be performed correctly or such a plant would not be practical. Still more significant is the feat of manufacturing the more than 100 parts for the frame in as many different places in the plant, to have them meet at one place on schedule, to piece them together at the rate of a complete unit every 8 sec., and to repeat this accurately ten thousand times in succession every day.

"The manufacturing building has a productive capacity of 450 assembled frames per hour, and in order to supply parts, each unit preceding the general assembly has a capacity of 450 pieces per hour. For similar reasons it is necessary to have the same capacity for the raw-material handling machines. Thus the inspection machines can handle 900 strips per hour, the pickling machines upward to 1,100 tons of steel per day, and finally the painting machines can turn out 450 frames per hour."[1]

This automatic plant is the last word in balance of departments, but any factory can approach this by using care in the selection and arrangement of equipment.

Arrangement of Service Centers.

Service centers include locker rooms and dressing rooms, wash rooms, showers and toilets, rest rooms, tool storage, and parts storage, which may include space for parts in process as well as finished units.

[1] REDLIN, A. W., Handling Materials in an Automatic Frame Plant, *Trans. A.S.M.E.*, MH-52-14, p. 101, September–December, 1930.

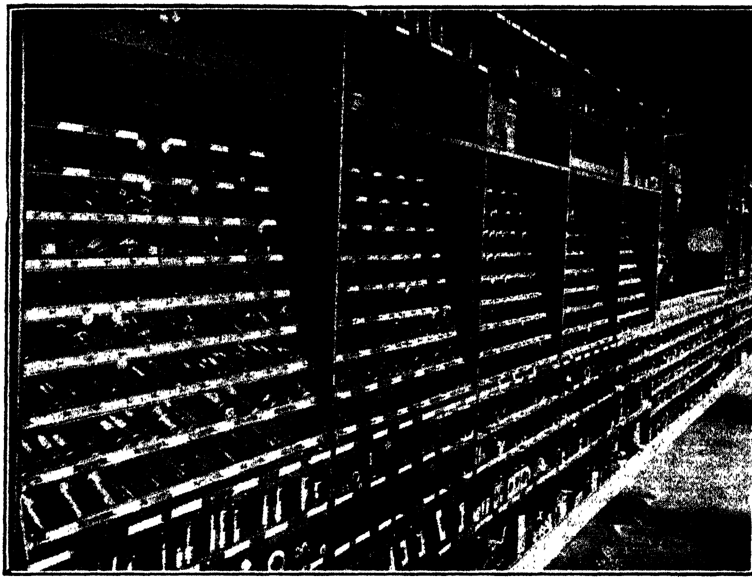


FIG. 29.—A tool room, showing method of storing small tools. (*Courtesy of the Lyon Metallic Manufacturing Company.*)

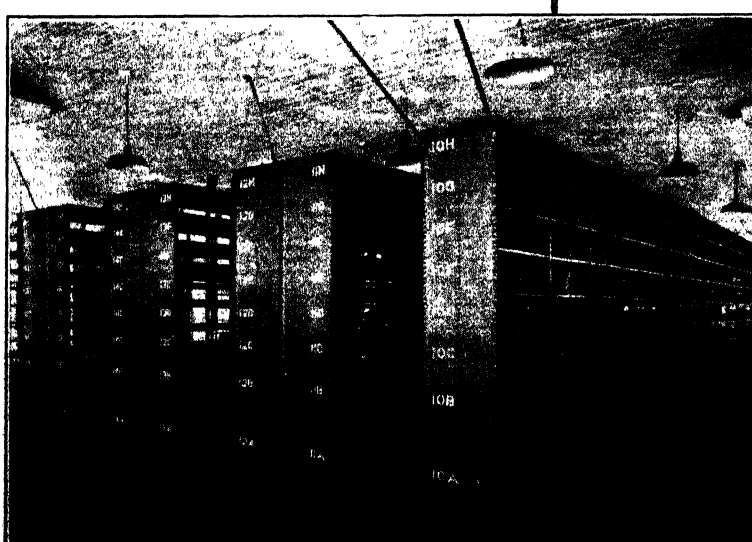


FIG. 30.—Pattern storage shelves of the Brown Lipe Gear Company. (*Courtesy of the Lyon Metallic Manufacturing Company.*)

Wherever possible it is well to place the wash rooms, elevators, and stairways in separate wings attached to the main buildings. Where a multistory building is used these would form a tower running from the first floor to the top of the building, and this arrangement not only frees the main manufacturing floor from these obstructions but materially aids in solving fire-protection problems. Where wash rooms are placed one above the other, considerable saving in plumbing cost will result.

In multistory buildings it is better to have locker and dressing rooms on each floor than to have one large room for this purpose

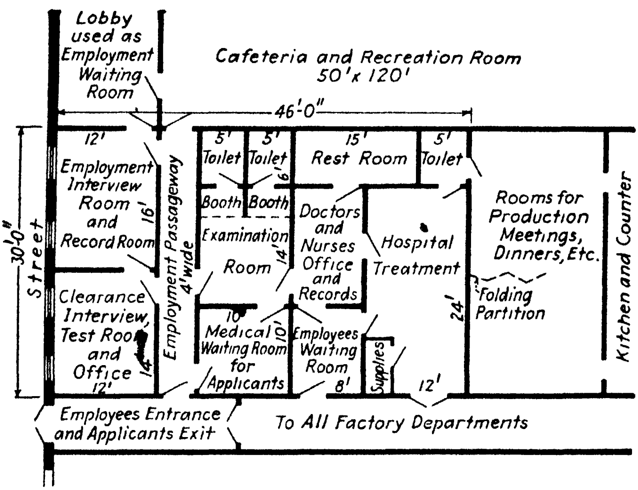


FIG. 31.—A well arranged layout for the employment and medical departments of an industrial plant. The Ballinger Company, Architects and Engineers. (*Courtesy of The Architectural Forum.*)

on the ground floor. By having separate rooms for each department or for each class of workmen, it is possible to lessen the confusion and congestion at the exits, stairways, and elevators at quitting time. Also, this arrangement tends to prevent theft in locker rooms where individual lockers are not provided for each employee. The location of the locker room in the department should be such that it will be natural and convenient for the worker on entering the department to go first to this room and change his clothes before ringing in his time card. This last point is insisted on by many managers, and if some thought is given to the location of these units from this angle the matter will take care of itself.

There are laws in some states requiring that a certain minimum number of units be installed in the wash rooms and toilet rooms per 100 workmen employed. It is better to install too many units than too few. Certainly provision should be made for additional units to be added as needed.

Rest rooms are always provided where women are employed and it is well to have this room separate from the other units. Often a large sun parlor or general recreation room is provided for the women employees in addition to the smaller rest rooms in the different departments. The large room is used at noon and

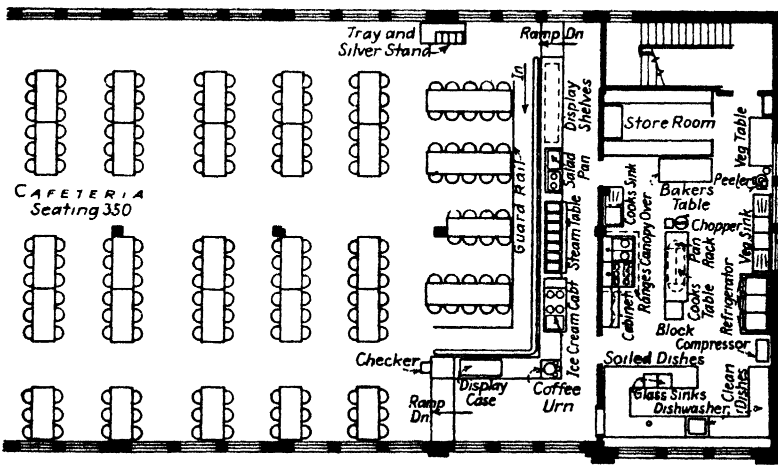


FIG. 32.—Plan of the kitchen and a portion of the cafeteria of the American Can Company, Chicago (*Courtesy of the Architectural Forum.*)

perhaps before and after working hours. In size it should be sufficient to accommodate all of the women workers in the building.

Tool rooms, which may include facilities for tool sharpening and repairing, should be located at convenient points in the factory. There is usually one central tool room and then a number of smaller tool cribs in different parts of the plant. By having an adequate number of these tool cribs it is possible to give better service to the worker at the window and also save him time in going from his work place to and from the tool crib.

Storage for parts in process should be located with the idea of reducing the handling as much as possible. Where the parts are bulky and heavy, they certainly would not be moved from one

floor to another or from one department to another just for convenience in storing. In plants making light units it is often advisable to have the storage rooms on the top floors and, by the use of gravity conveyors, to send the material down to the assembly lines or benches as needed. In most cases parts are stored in enclosed rooms; however, it is sometimes more desirable to mark off a space on the floor in each department to be used for temporary storage of parts, jigs, fixtures, and other similar

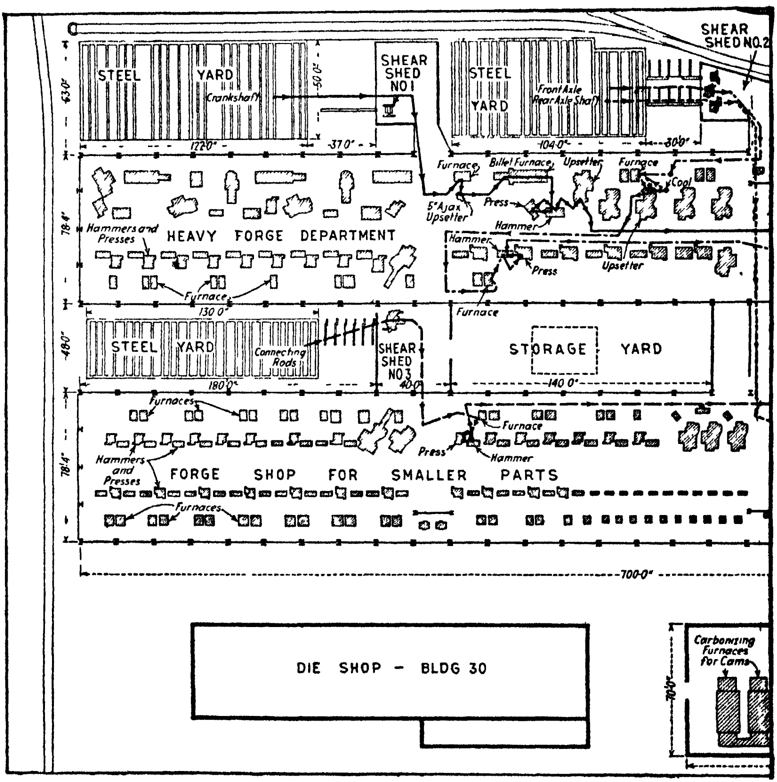


FIG. 33.—General plan of forge shop at the Willys-Overland plant, showing forged parts. Straight-line production has been adopted

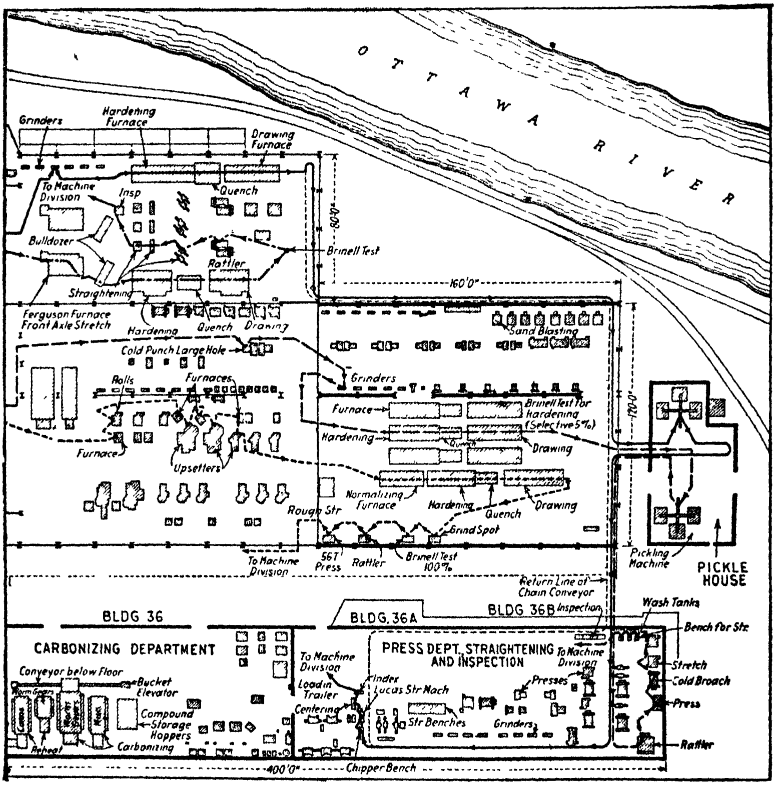
apparatus, while they are waiting between operations. Mezzanine floors are very convenient for material storage as well as for other service units. This arrangement often prevents congestion and saves considerable floor space.

In plants where dining rooms and cafeterias are provided it is often desirable to locate these on the first or second floor or in

well-lighted basement rooms. A central location with plenty of light and air as well as ease of accessibility is another necessary requirement. A dining room can be arranged most satisfactorily if the room is rectangular in shape.

Direct-line Layout.

Where the machines in the department are grouped according to the kind or according to the nature of the work being done, it



location of departments, layout of equipment, and routes followed by typical throughout. (*Courtesy of the Willys-Overland Company.*)

is always desirable to provide for a smooth, direct flow of work from one machine to another. If a multistory building is used, the direction of flow may be from the first floor to the top, the raw material being stored on the first floor and the first operations being performed on this floor. In other types of industries it is desirable to move the raw material directly to the top floor for

storage, gravity then being used for moving the processed material from floor to floor. The finished product would be stored on the first floor from which it would later be shipped.

In a recent layout at the Mansfield plant of the Westinghouse Electric and Manufacturing Company, provisions were made to manufacture safety electric switches in large quantities. A two-story building was used and the storerooms were located on the second floor, gravity being used to move the material to the desired points on the lower floor for processing and assembly operations.

While crowding machines together is not desirable, it is always good layout to have the moves from one machine to the next as short as possible. Figure 33 shows a forge shop arranged to give short moves and straight-line layout, and this is not a continuous industry.

Internal and External Transportation.

The methods of handling materials during the process of manufacture will be different in a large factory of the continuous type from that in a jobbing shop. Belt and roller conveyors and special handling equipment can be employed when mass production warrants the expenditure and when the equipment will be used to capacity. In the smaller factories, trucks, cranes, hoists, and various kinds of similar equipment will find extended use.

The material handling between buildings and in the yards and outdoor storage areas will be done by narrow-gage railroad, gasoline and electric motor trucks, tractors, etc. Provision must be made for the switching, loading, and unloading of freight cars and this is a part of the transportation problem.

The proper selection of materials handling equipment is of such great importance to practically every factory that a separate chapter has been given to the discussion of this subject.

Provision for Future Expansion and Growth.

It is well to plan a building much larger than the present business requires and then actually build only sections as they are needed. The layout of the Dunlop Tire and Rubber Corporation is shown on the following page. From Figs. 34 and 35 it is apparent that provision has been made for additions to the plant when they are needed.

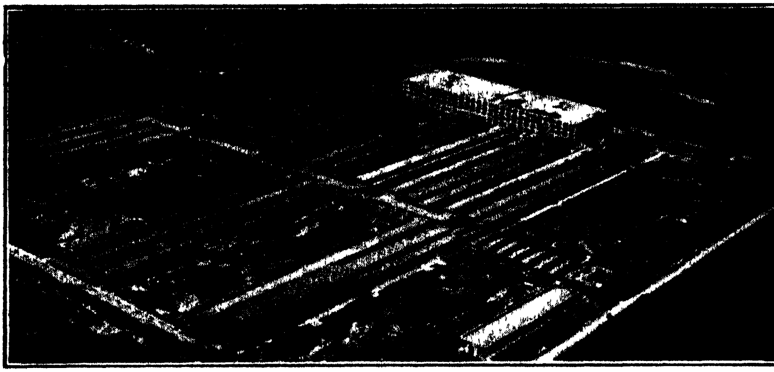


FIG. 34.—Aerial view of the plant of the Dunlop Tire and Rubber Corporation showing the arrangement of buildings and provision for future expansion. (*Courtesy of the Dunlop Tire and Rubber Corporation.*)

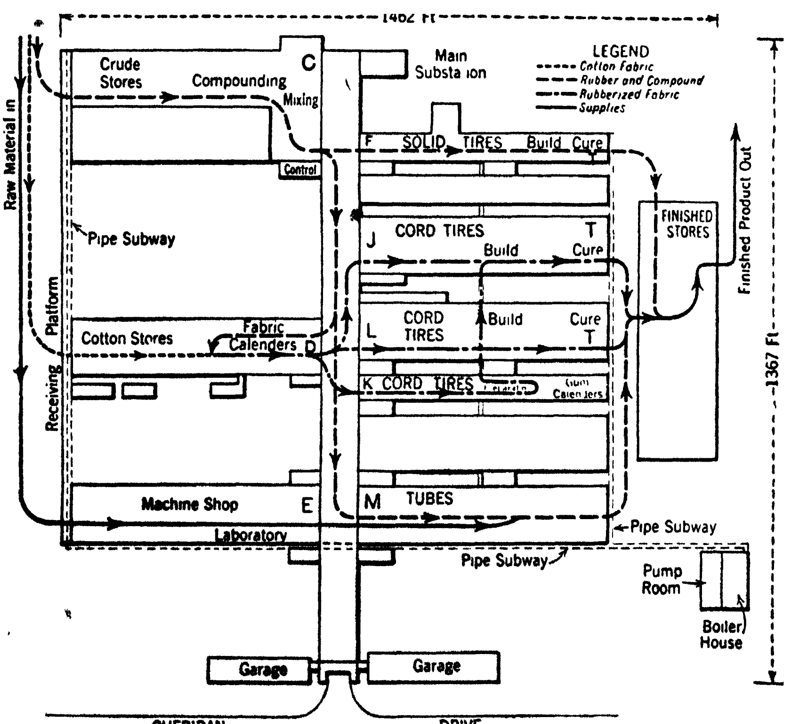


FIG. 35.—Layout of plant and routes of materials. (*Courtesy of the Dunlop Tire and Rubber Corporation.*)

In making additions, consideration must be given to the existing arrangement of the departments, equipment layout, service centers, lines of transportation, etc. These should be disturbed as little as possible by additions of new buildings or wings to the present structure. In some cases it is possible to add additional stories, and where this is planned, provision must be made in the original foundations and column strength for the additional load. Where the cost of the ground permits, the expansion will be made laterally, and additions should be connected up with the present buildings in as efficient manner as possible.

Safety and Fire Protection and Industrial Codes.

Accident and fire prevention are administered by trained men who have an important position in the modern factory organiza-

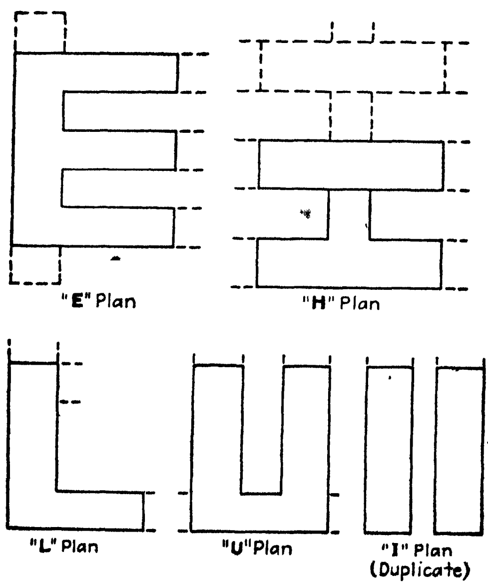


FIG. 36.—Possible directions of expansion where buildings are grouped.

tion. The director of safety, as he is often called, is assisted by a competent staff and he is responsible for reducing the hazards to a minimum in and around the factory. A fire chief is maintained on the staff if the nature of the business warrants it, and adequate fire-fighting equipment and personnel should be provided.

It is not the purpose here to explain the organization, direction, or maintenance of a department for the prevention of fires and accidents in the factory but it is the plan to explain certain fundamental rules and principles that must be considered in the construction and layout of an industrial plant.

1. It is necessary to comply with all local and state labor laws and rules and with the industrial codes.

2. It is desirable to offer as much protection as possible in order to lower fire insurance rates, to reduce the cost of workmen's compensation, and to lower the premium paid where group insurance is used.

3. It is desirable to go beyond the requirements of the law in fire and accident prevention to provide every means possible to make the factory a healthful and attractive place in which to work, to provide adequate sanitary equipment, and to incorporate such additional features, as lunch rooms, cafeterias, reading rooms, club rooms, first-aid rooms, and hospitals, as will directly or indirectly benefit the workmen.

State and Local Industrial Codes.

Most states and cities are very liberal as to fire, safety, and sanitary requirements, but some have rather stringent and well-defined laws which must be observed. The industrial codes of the different states and cities will be reviewed and the most important rules will be given.

There are certain unwritten laws which are used in construction work and in factory layout. These rules and practices are the results of many experiments and long experience and seem to be almost universal in use. Such items as might be termed "good practice" will also be given.

Industrial Codes

1. **Doors.**

   a. All doors shall be of fireproof construction and be of the self-opening type.

   b. Horizontal exits shall have an unobstructed width of not less than 44 in.

   c. All doors shall open outward.

   d. The width of the hallways and exit doors leading to the street level shall not be less than the aggregate width of all stairways leading to them.

2. Exits.
   a. There shall be not less than two means of exit remote from each other, one of which on every floor above the ground floor shall be an interior enclosed fireproof stairway or an exterior enclosed stairway, and the other a stairway or a horizontal exit.
   b. No point in any floor area in an unsprinkled building shall be more than 100 ft. (150 ft. if sprinkled) from one such means of exit.
   c. Whenever any floor area exceeds 5,000 sq. ft. there shall be provided one additional means of exit as described for each 5,000 sq. ft. in excess of 5,000 sq. ft. N. Y. Industrial Code, Art. 79-a, Sec. 2.

3 Factory Construction.
   a. All buildings more than four stories in height shall be of fireproof construction.

4. Elevators.
   a. Doors to elevators must be fireproof, full width, and have wire-glass windows.
   b. Elevators (freight or passenger) must be enclosed in a fireproof shaft. All openings shall be provided with self-closing gates or sliding doors.
   c. It is not good practice to wind stairways around the elevator shaft.
   d. Freight elevators are 8 by 10 ft., 10 by 10 ft., or 10 by 12 ft.

5. Stairways.
   a. Stairways shall be constructed of incombustible material and shall have an unobstructed width of at least 44 in. through their width except that handrails may project not more than 3½ in. into such width.
   b. Stairways shall be not more than 12½ ft. in height between successive landings.
   c. The treads shall be not less than 10 in. wide exclusive of nosing, and the rise shall be not more than 7¾ in.
   d. No stairs with "winders" shall be allowed except from one floor to another
   e. Every stairway shall be enclosed on all sides by fireproof partitions extending continuously from the lowest story to 3 ft. above the roof.
   f. All stairways serving as required means of exit shall extend to the roof and shall lead continuously to the street or to a fireproof passageway independent of other means of exit from the building opening on a road or street.
   g. Provision shall be made for the adequate lighting of all stairways by artificial light. N. Y. Labor Law and Industrial Code, Art. 79-a, Sec. 3, p. 55.

6. Partitions.
   a. All partitions in the interior of the buildings of fireproof construction shall be of incombustible material.

7. Fireproof windows.
   a. Fireproof windows shall be windows constructed of metal frames and sash covered with metal and provided with wire glass and of the automatic, self-closing type.
8. Number of occupants.
   a. Not more than 14 persons per 22-in. width of stairway, and no allowance is made for any width less than 22 in. (multiples of 22 in. only).
   b. One additional person allowed for each 16 in. over 10 ft. of ceiling height and one for each 22-in. width of stairway, also one additional person may be permitted for each 5-ft. landing.
   c. The number of persons may be doubled if an automatic sprinkler system is installed.
9. Exhaust fans.
   a. Where poisonous or injurious dust, fumes, or gases shall be created by machinery or material in process of manufacture, provision shall be made for proper hoods and pipes connecting with exhaust fans of sufficient capacity to remove dust, fumes, or gases at their point of origin and prevent them from mingling with the air in the room. Penn. Labor Laws, Sec. 11.
10. Washrooms, lockers, and lavatories.
   a. Location as convenient to the shop as possible, with separate rooms for each but grouped on each floor.
   b. Wash room large enough to handle one-half of the people employed on the floor. (N. Y. Code requires one wash basin with water-supplied faucet for each 20 employees employed at any time.)
   c. Locker room shall contain a locker for each person. Separate rooms must be provided for women. Where more than 5 and not more than 10 females are employed, the floor space shall be not less than 60 sq. ft., and for each additional person not less than 2 sq. ft. N. Y. Code, Rule 158.
   d. Each locker and wash room shall have at least one window or one skylight opening directly to the outdoor air.
   e. The number of lavatories and closets required shall be based upon the maximum number of persons employed at any time on the given floor.

Number of persons	Closets	Ratio
1 to 15	1	1:15
16 to 35	2	1:17.5
36 to 55	3	1:18.3
56 to 80	4	1:20.0
81 to 110	5	1:22.0
111 to 150	6	1:25.0
151 to 190	7	1:27.0

Thereafter accommodation shall be at the rate of one closet for every 30 persons. N. Y. Code, Rule 100, 101, 102, Law 293, Rule 148.

11. Machinery to be safeguarded.
    a. All vats, pans, saws, planers, cogs, gearing, belts, shafting, setscrews, grindstones, emery wheels, flywheels, and machinery of every description shall be properly guarded. The floor space of no working room in any establishment shall be so crowded with machinery as thereby to cause risk to life or limb of any employee nor shall there be in any establishment machinery in excess of the sustaining power of the floors and walls thereof. Penn. Labor Laws, Sec. 11.

Provision for Proper Lighting, Heating, and Ventilation.

The benefits to be obtained from proper lighting are so great and the principles and requirements are so simple that the executive need not have a large technical background to understand them. Separate chapters will be given to the whole subject of factory lighting.

Heating, ventilation, and air conditioning require considerable study to bring about greatest economy in operation and to give just the desired degree of control. The comfort of the worker is vital, and a combination of proper temperature, humidity, and air circulation should be maintained to give uniform and proper condition to the air.

Many industries require special air conditioning and very closely regulated temperature and humidity in order to give uniform quality to the product being manufactured. In some cases the success of the process hinges solely on the maintenance of predetermined air conditions and warrants an elaborate and costly installation of equipment to give uniform air conditions the year round. Bakeries, paper mills, textile mills, chemical plants, and printing establishments might fall under the above classification.

The question of selecting the proper equipment for a particular plant is one requiring considerable technical knowledge and experience in the field of heating and ventilation. In most cases the executive will do well to use consulting service or turn the problem over to competent engineers who are employed on the staff for the purpose.

The Use of Templets in Layout.

Few manufacturers today would make changes in the layout of their equipment or arrange a new layout without first making

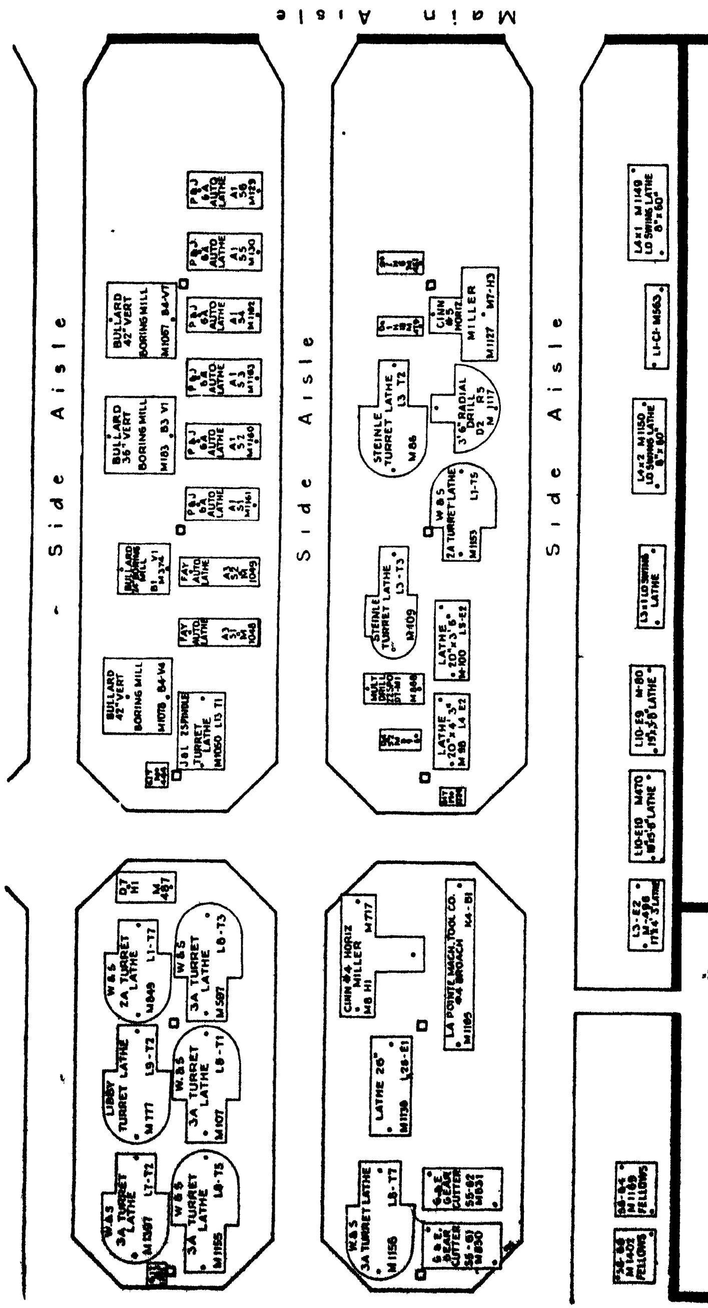


FIG. 37.—Cardboard templets show the proposed arrangement of equipment in a section of the manufacturing department. (*Courtesy of the Caterpillar Tractor Company.*)

a careful drawing of the exact location of the machines on the factory building floor plans.

The use of paper or cardboard templets of the machines, cut out to the same scale as the factory building floor plans, will aid in finding the most suitable arrangement of the equipment and help visualize the layout on the drawing board.

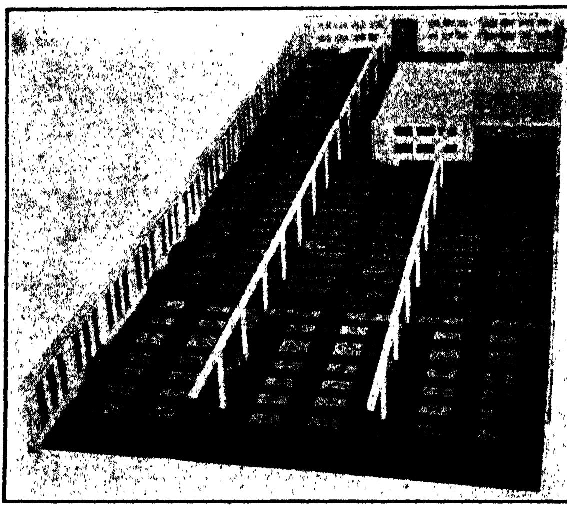


FIG. 38.—Models of desks, filing cases, and office equipment used in the layout of the fourth floor of the motor building of the Otis Elevator Company. Locker rooms and the stationery and mailing division are shown in the upper right-hand corner. (*Courtesy of the Otis Elevator Company.*)

Figure 37 shows proposed changes in arranging production equipment as it was being worked out at the Caterpillar Tractor Company factory. The Otis Elevator Company went so far as to use scale models in planning their new office building, as Fig. 38 shows.

CHAPTER IV

MATERIALS HANDLING

Provision for the transportation of materials within a factory is one of the major factors in plant layout. In some industries such as a rolling mill or a continuous plate-glass plant the entire process is built around the handling equipment. The question of factory transportation is generally considered of prime importance in plant location and may even determine the particular site that is selected for the factory. Some industries find it economical to make use of gravity in solving their materials-handling problems. Figure 39 shows the layout of a furniture

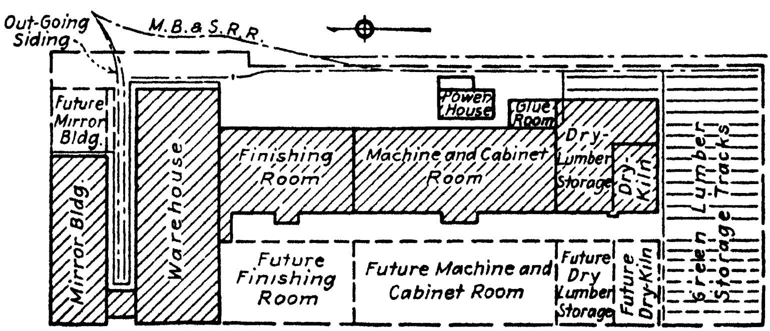


FIG. 39.—Furniture manufacturing plant with gravity equipment prevailing in the materials-handling system. (*Courtesy of Factory and Industrial Management.*)

manufacturing plant which is so arranged that the floor line is actually pitched from 0.5 to 1 per cent, from the green lumber storage tracks at one end of the plant to the shipping department in the other. This permits the movement of material through the factory by gravity alone.

Factors Affecting the Selection of Handling Equipment.

It is not an easy task to provide the most effective and most economical materials-handling equipment for a factory. It might seem that there is such a wide variety of equipment to choose from that the problem would not be difficult, but, as a rule, each

one of the different materials-handling devices has particular advantages that the others do not have. Therefore it becomes necessary to examine each existing problem very carefully and to analyze the situation from a number of angles such as:

1. Fitting the handling devices to the production equipment so that the plant will operate as one unit. This will require the coordination of manufacturing equipment and handling devices in the different departments. As a result there will probably be a decrease in the production space required, permitting a greater output in the same area.

2. The more effective use of labor may be accomplished in three ways. First, by the elimination of hand labor wherever economically possible. Second, by increasing the amount of material moved per man. And, third, by delivering material to the worker as fast as he needs it, which will result in the saving of waiting time of both the man and the machine.

3. By reducing the manufacturing cycle, the inventory of goods in process is decreased, which not only releases the capital that would otherwise be tied up but also releases storage space for other purposes. Then, too, the control of production is facilitated, steadier deliveries are assured, and greater economy in purchasing may logically result.

4. The flow of material should be as direct as possible. This is not so difficult to arrange in a straight-line layout, but even where machines of a kind are grouped in separate departments it is often possible to make improvements in handling economy by a careful study of the relative location of departments with respect to materials handling.

5. Coordination of materials handling in the plant to shipping methods, where skids, racks, or special containers are used, may result in a considerable saving in both time and money to the shipper as well as to the customer. The use of skids for shipping is rapidly gaining favor.

A slight change in the design of the product may facilitate the handling. The accident hazards of one handling device over another may influence the selection of a particular type. A study of the total weight of material and equipment that must be handled to produce each pound of finished product is another angle to be considered in analyzing the problem.

"In the foundry of the Blake and Knowles Works of the Worthington Pump and Machinery Corporation, for example, a careful

analysis was made, and it was determined that 152 tons have to be handled for every ton of brass castings. For making 1 ton of iron castings, 206 tons of material have to be handled. These figures include the handling of the metal to and from the melting furnace, all handling of materials used in core making, handling of sand equipment in molding, handling in the process of cleaning and snagging, and delivery to the shipping room."[1]

Harold V. Coes suggests that the selection of a particular kind of materials-handling equipment should be predicted on the following data:

a. The nature of the commodity or commodities to be handled.

b. The size, shape, weight, relative fragility, etc.

c. Amount to be handled per hour, per day, etc., in (1) pieces, (2) pounds, (3) tons, or (4) units.

d. Distance the parts or commodities are to be moved horizontally or vertically or both.

e. Type of container, skid, rack, etc., on which parts of the commodity are received at the point of translation.

f. Standardization of factors in item *e*.

g. The number of times the part or commodity is now being handled.

h. The effect of speed of translation on the article or articles to be handled.

i. Production rate of the equipment at the originating point of translation.

j. Sequence of manufacturing operations.

k. Interplant and department relationships.

l. Location of raw, process, and finished stock rooms.

m. Location of incoming and outgoing railroad spurs, roads, etc.

n. Cost of unskilled common labor.[2]

Handling by Machinery Instead of Men.

The following rules have been suggested by R. H. McLain of the General Electric Company to show when greater economies might be expected to result from the use of machinery instead of men unaided by mechanical devices:

[1] EIDMANN, F. L., Materials Handling as an Aid to Production, *Trans. A.S.M.E.*, vol. 50, No. 5, MH-50-4, p. 2, January–April, 1928.

[2] COES, HAROLD V., Some Fundamental Principles of Materials Handling, *Mech. Eng.*, vol. 51, No. 10, p. 748, October, 1929.

1. Where three or four men are working together on one job for 2 hr. at a time, even though the work is not performed more than three or four times a week.
2. Whenever a man has to lift anything from his feet to a point above his head.
3. Whenever a man has to lift more than 50 lb. from his feet to his shoulders.
4. Whenever a man has to lift more than 100 lb. from his feet to his waist.
5. Whenever a man has to lift more than 150 lb. from his feet to his knees.
6. Whenever a man has to stand in one place steadily moving material for over 30 min.
7. Whenever a man has to move material sidewise more than 6 ft., that is, two steps.
8. Whenever a man or a group of men, although moving around in a small radius, has to move more than 10 tons of material per hour.[1]

Classification of Materials-handling Equipment.

Materials-handling equipment may be classified in various ways, but the one given in Table V*a* is very satisfactory. The main divisions are:

1. Lifting and lowering devices (vertical motion).
2. Transporting devices (mainly for horizontal motion).
3. Devices which lift, lower, and transport (combined vertical and horizontal motion).

Table V*a*.—Classification of Materials-handling Devices*

Type	Main use
1. Lifting and lowering devices (vertical motion):	
a. Block and tackle	Local hoisting
b. Winches	
Hand, Power	Cargo handling

* Stuebing, W. C., The Field of Material Handling, *Mfg. Ind.*, vol 13, No. 3, p. 169, March, 1927.

[1] A Brief Directory of Material Handling Apparatus, by R. H. McLain, *Gen. Elec. Rev.*, vol. 24, No. 4, p. 306

TABLE Va.—CLASSIFICATION OF MATERIALS-HANDLING DEVICES.—(*Continued*)

Type	Main use
c. Hoists (fixed)	
Chain, Air, Electric	Local service in foundries, machine shops, woodworking shops, etc.
d. Skip hoists	Coal and ash handling
e. Hoisting engines	Construction service
f. Elevators	
Hand, Belted, Hydraulic, Electric, Special	Multistory manufacturing plants, serving charging platforms in foundries, etc.
g. Cupola chargers	Foundries
2. Transporting devices (mainly for horizontal motion):	
a. Wheelbarrows	Yard work
b. Hand trucks	
Stevedore type	Shipping; freight service
Box type, Rack type, Platform type	Special service in manufacturing plants
c. Industrial railways and equipment (narrow gage)	Heavy handling
d. Tractors and trailers	
Electric, Gasoline	Mass movement of products
e. Tructractors	Rapid and severe service in manufacturing plants
f. Railway equipment (standard gage)	Transportation service
g. Car pullers	Spotting freight cars
h. Aerial tramways	Long distance conveying
i. Skids for rolling pipe, etc	Storage and shipping
j. Pipe lines	Fluids
k. Pumps	Fluids
3. Devices which both lift, or lower, and transport (combined vertical and horizontal motion:[1]	
a. Chutes	Gravity handling

[1] Includes those devices, usually traveling horizontally, which pick up material; also those which usually provide for elevation during horizontal travel, such as ramps, trestles, etc.

TABLE Va.—CLASSIFICATION OF MATERIALS-HANDLING DEVICES.—(*Continued*)

Type	Main use
b. Hoists with trolleys running on overhead rails	
Chain, Air, Electric	General service in manufacturing plants
c. Lowerators	In conveyor systems
d. Lift trucks	
Hand, Electric	Rapid service on good floors or roadways in all types of manufacturing plants
e. Small crane trucks	
Electric, Gasoline	Lifting and transporting fairly heavy loads
f. Portable elevators or tiering machines	Stacking service in storerooms
g. Autotrucks	Heavy trucking inside or outside plant
h. Conveyors:	
Apron, Bar, Barrel, Belt, Bucket, Pivoted bucket	Bulk or package materials according to specific nature
Chain	Unit products
Disc scraper or flight, Drag scraper	Bulk material
Package	Unit or package products
Portable:	
Belt, Bucket	Bulk materials
Roller	Unit parts or package
Pneumatic:	
Suction, Pressure	Loose and light materials
Roller type:	
Gravity, Power driven	Unit or package products
Screw	Loose materials
Slat	Unit products
Spiral:	
Chute, Roller	Unit or package products

TABLE Va.—CLASSIFICATION OF MATERIALS-HANDLING DEVICES.—(*Continued*)

Type	Main use
Production-line conveyors:	
Assembly type (as in automobile industry)	Machine assembly, radio assembly, etc.
Sacking type (as in cement mills)	Cement packing, etc.
i. Tram-rail systems	Handling units or assemblies in manufacturing plants
j. Cranes:	
Jib:	
Hand Electric	Local service on heavy shop work
Floor operated:	
Hand Electric	Limited travel on heavy shop work
Cage operated:	
Monorail Bridge, overhead traveling Gantry Ore	Long distance travel in shops and yards, loading vessels and cars, usually on heavy work
k. Locomotive cranes	Yard service in manufacturing plants, on construction, etc.
l. Car dumpers	Bulk shipments
m. Ramps	To give access to different levels
n. Trestles	For storage of materials

Few manufacturing concerns would be likely to use all of the materials-handling devices named in the above table. E. J. Mills, superintendent of internal transportation of the Pittsfield Works of the General Electric Company lists in Table V*b* the kind and amount of their present trucking equipment. This plant manufactures motors, transformers, and other electrical equipment. It employs over 6,000 workers.

Their general scheme of handling is:

1. To use electric tractors and trailers as the primary handling equipment wherever possible for both interplant and interdepartmental handling.

2. To use electric lift and baggage trucks, in connection with either skid platforms or tote boxes, as a secondary line of handling equipment where quantities are smaller, where upper floors must

TABLE V*b*.—MATERIALS-HANDLING EQUIPMENT AT THE PITTSFIELD PLANT

Item	Type of equipment	Number of units
1	Electric tractors	18
2	Gasoline tractors	4
3	Electric lift and high lift trucks	25
4	Electric baggage trucks	15
5	Trailers, 2 to 8 tons, with a few 20-tons capacity; 75 per cent are standard and 25 per cent are special	598
6	Lift truck tote boxes (used mostly in storage)	1,000
7	Lift truck platforms	400
8	Hand-lift trucks	21
9	Electric traveling cranes	1
10	Electric locomotive	1
11	Locomotive crane	1

be reached by means of freight elevators, and where equipment is closely concentrated and aisle spaces are limited.

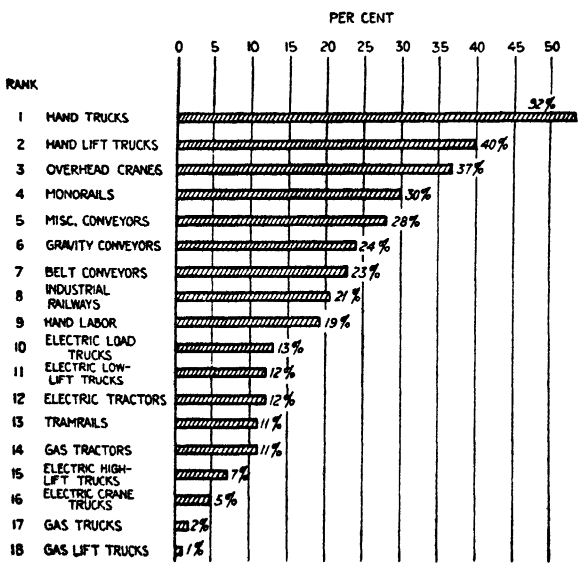


FIG. 40.—Proportion of companies using each type of materials-handling equipment.

3. To use hand-lift trucks for local handling to individual machines from central delivery points in the various departments.

4. To use hand trucks of various types and sizes, stevedore trucks, and similar apparatus only at local points and for miscellaneous purposes.

5. To use overhead traveling cranes, locomotive cranes, and electric locomotives and equipment of this character for loading, unloading, and transporting heavy objects and bulk materials within, without, or between the various buildings.

The Society for Electrical Development, Inc., has sponsored a field survey in which the entire question of ownership of materials-handling equipment is a part. Figure 40 shows the proportion of companies using different types of materials-handling equipment in their plants.[1]

A brief description will be given of some of the more common devices used for materials handling.

Platform Trucks.

The ordinary four-wheel platform truck is standard equipment in many factories. This is true because of its general utility and also because of the supposedly low initial cost and the relative low upkeep. In recent years the hand- and power-lift trucks have been developed, and they are fast replacing the ordinary platform truck.

Lift Trucks.

All lift trucks might be classified as (1) hand or (2) power trucks. The power-operated truck has the vertical movement of the platform as well as the horizontal motion of the truck itself actuated by either an electric motor or a gasoline engine mounted on the truck. This work is done by the truckman in the case of the hand-lift truck.

Hand-lift Trucks.

The basic feature of this truck is the separation of the platform from the chassis. That is, the platform is built in the form of a skid having four legs which carries the load from 8 to 12 in. above the floor. Figure 42 shows hand-lift trucks and skid platforms in use in a storeroom. Since the skid carries the load, the truck (chassis) can be backed under the platform, the truck handle lowered, the platform with its load raised several inches

[1] Progress in Materials Handling, *Trans. A.S.M.E.*, vol. 51, No. 3, MH-51-1, p. 5 January–April, 1929.

above the floor, and it can then be moved away on the truck. When the load has reached its destination, the platform can be lowered on to the floor again and the truck can be drawn out and used for other work. The skid platform can be adapted to the

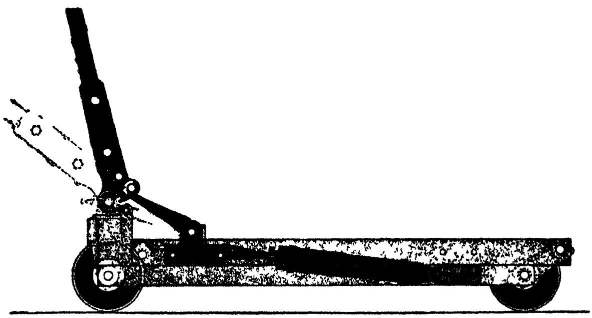


FIG. 41.—Hand-lift truck, showing positive platform elevating connection and positive check.

FIG. 42.—Hand-lift trucks and skid platforms in use in store room. (*Courtesy of the Lewis-Shepard Company.*)

handling of practically any kind of load. It can be had in the standard platform type or with stakes, end gate, tote box, rack, tray, or any other type required.

The chassis or truck, as it is called, is of metal construction with three or four wheels, as the case might be. The load capac-

ity of the truck ranges from 500 to 10,000 and even 20,000 lb., and all trucks are capable of being operated by one man.

Skid Platforms for Freight Shipment.

There were loaded, in 1927, about 19,400,000 car loads of freight exclusive of bulk goods such as coal, grain, liquids in tank cars, etc.; and if average car loadings reached 30 tons per car, the loading and unloading charges for these cars regardless of the handling within the plant totaled some $870,000,000.[1]

It is possible for manufacturers and railroad companies to make radical reductions in this figure by the use of skid platforms for the shipment of many kinds of freight. The records of the Champion Coated Paper Company show that a 50-ft. box car is loaded with paper on skids in 45 min. using two men. The same loading formerly took seven men 3 hr.

"A manufacturer of springs for automobile seats has a plant located in Ohio; his springs are used by an automotive plant in Detroit. At the end of his production line will be found steel 'stock boxes' on legs into which the small springs drop upon completion of the last operation. These springs are not touched until they are removed from the skid box by the workman on the production line in the plant of the Detroit manufacturer. The box of springs weighing approximately 4,000 lb. is taken from the production line and loaded in a box car by means of an electric lift truck. The material, still on skids, is then hauled to Cleveland where it is transferred to the boats of the Detroit and Cleveland Navigation Company by power trucks. Upon arrival at Detroit the skid load is placed on a motor truck and hauled to the factory where it goes either to storage or direct to the production line. Six handlings by power and at a small percentage of the former cost have been made."[2]

The Orange Avenue terminal at Cleveland uses lift trucks, and the following statement gives some idea of their uses and the savings that result:

Incoming goods are transferred from cars and throughout the warehouse by means of lift trucks. Most of the goods not already on platforms when received at the terminal are placed on

[1] Crockett, C. B., Economic Aspects of the Shipment of Materials on Skid Platforms, *Trans. A.S.M.E.*, vol 51, No. 23, MH-51-9, p. 73, September–December, 1929.

[2] Crockett, C. B., Saving a $100,000.000 Shipping Loss, *Mfg. Ind.*, vol. 16, No. 4, p. 255, August, 1928.

them during the course of unloading. Accurate costs of materials-handling methods between past and present showed a reduction in many cases from $1.08 to $0.33 per ton.

It is necessary to standardize the skid platform sizes if they are to be of the greatest benefit to all concerned. At the preliminary conference of manufactures held in Washington in 1928 under the direction of the Division of Simplified Practice of the Bureau of Standards, the following recommendations were made:[1]

1. That the height of lifting platforms in the lowest position should be either 7 or 11 in.

2. That the maximum width of lifting platforms should be 27 in.

3. That the minimum clearance between underside of skid platform and top of lifting platform of truck should be ¾ in.

No definite action was taken to specify exact sizes for platforms, but the following tentative sizes seem desirable:

a. 33 by 50 in.

b. 50 by 66 in.

These sizes allow the platforms to fit two or three wide in a Standard American Railway Association box car.

Power-lift Trucks.

The power-lift truck has practically all the advantages of the hand-lift truck except the initial cost, and, besides, it furnishes a rapid means of transporting the platform and its load from one place to another in the factory. One man with a power-lift truck can do the work of several men with the ordinary platform truck or even with hand-lift trucks. There are two kinds of power-lift trucks: (1) gasoline motor driven and (2) electric storage-battery driven. The gasoline-motor-driven lift truck is similar in general construction to the electric-lift truck. Mechanically it is more difficult to transmit the power from the gasoline engine to both the lifting mechanism and the running gears than it is to mount electric motors at the desired points of power application. On the gasoline truck the platform is raised and lowered by a hydraulic cylinder located under the truck, and the pump supplying it operates only while the load is being raised or lowered.

[1] Skid Platforms—Simplified Practice Recommendations, R95-28, p. 7, U. S. Bur. Standards.

The truck is driven on the front or small wheels and is steered with the large rear wheels. There are several outstanding advantages of the gasoline-driven truck. First, this truck is capable of 24-hr. service. There need be no idle period in which to charge or boost batteries as in the case of the electric truck. The gasoline motor-driven truck can go farther from its base and is thus adapted to outdoor service. However, it has a greater number of working parts and perhaps is not so nearly "foolproof" as the electric truck. It gives off exhaust gases and because of fire insurance rulings cannot be used in warehouses. It is

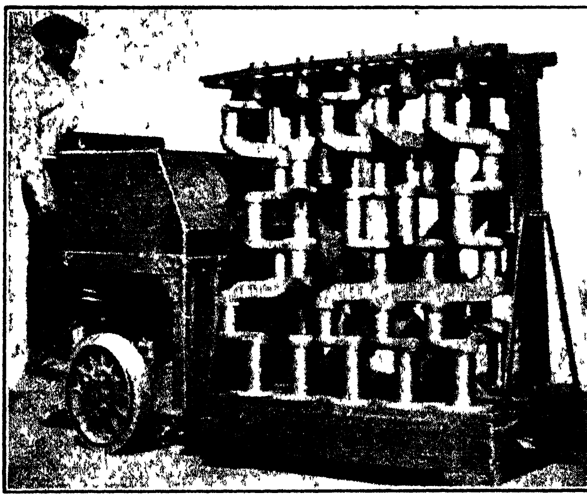


FIG. 43.—Specially designed skid platforms are used for handling and storing crankshafts in this factory. Motive power is supplied by electric-lift trucks. (*Courtesy of Factory and Industrial Management.*)

noisier than the electric truck and is more cumbersome, requiring slightly more turning room. For outdoor work, long hauls, and heavy loads the gasoline motor-driven truck might have an advantage over the electric truck.

The electric-lift truck is driven by a series wound direct-current motor connected to a set of batteries mounted on the truck, usually operating at about 35 volts. Often two motors are used, one for driving the truck and the other for raising and lowering the platform. This gives greater flexibility, fewer parts, and perhaps makes the truck easier to operate and nearer "foolproof." The steering mechanism is connected to both the front and the rear wheels, which permits short turning radius. Both

the standard electric and gasoline trucks are built for speeds of from 4 to 8 miles per hour on the level. The most common type of electric-lift truck is rated at 4,000 lb. capacity; however, they may be had in 6,000- to 10,000-lb. sizes. The trucks are capable of taking a 10 to 12 per cent grade under load. The standard height of the truck platform is 11 in. when in the lowest position, thus lifting the skid platform about 5 in. clear of the floor.

Analysis of Operating Costs of Trucks.

In order to show the effect that (1) the length of haul and (2) the amount of time a piece of equipment is in service has on the cost of operation, curves in Figs. 44, 45, and 46 are included. These curves are based on an assumed case where a gasoline or electric truck replaces four men at $3.50 per day and assumes that the men can be employed productively when not handling material.

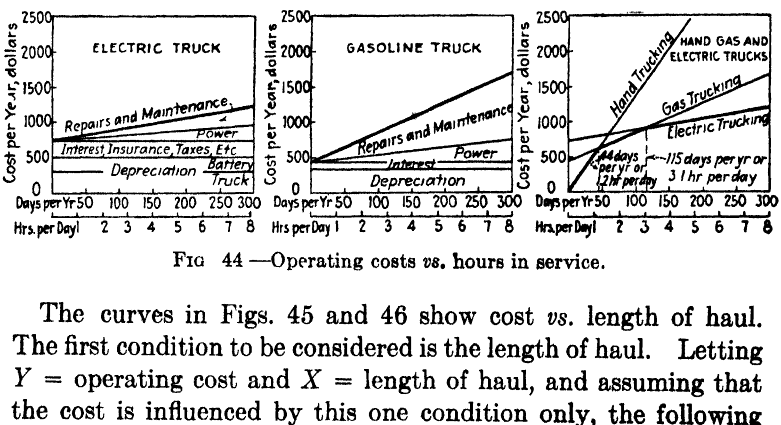


FIG 44 —Operating costs *vs.* hours in service.

The curves in Figs. 45 and 46 show cost *vs.* length of haul. The first condition to be considered is the length of haul. Letting Y = operating cost and X = length of haul, and assuming that the cost is influenced by this one condition only, the following formula is suggested by Crockett and Payne:[1]

$$Y = A + \frac{B}{X} + C\frac{X}{r}.$$

The three terms included in the cost formula are:

1. The fixed cost represented by A.
2. The cost of the equipment when idling, being a constant B which represents the hourly cost of the truck when stopping for

[1] CROCKETT, C. B., and H. J. PAYNE, Operating Costs of Electric Industrial Trucks and Tractors, *Trans. A.S.M.E.*, vol. 50, No. 5, MH-50-3, p. 5, January–April, 1928.

short periods, times the time idle which is inversely proportional to the length of haul. The second term may then be represented as B/X. For hand or electric trucks $B = O$.

3. The third term is the cost of the machine when moving. This term is a constant C representing the cost per hour when running, corrected so that the variables remaining are only length

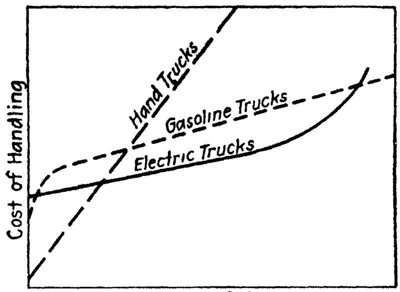


FIG. 45.—Cost *vs.* length of haul.

of haul X and the speed of the truck r. The influence of speed is not seen in the cost until the hauls are of considerable cost.

The analysis of the different costs is shown in the curves (see Figs. 44, 45, 46).

The High-lift Electric Truck.

The high-lift electric truck, or tiering machine, is a modification of the power-lift truck and it may be used to lift the skid plat-

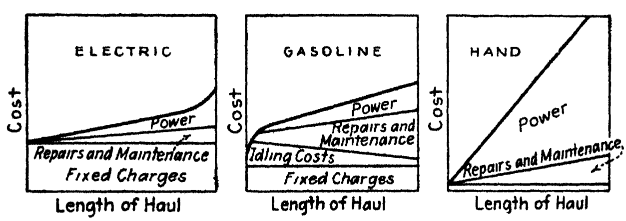


FIG. 46.—Elements of cost *vs.* length of haul.

form from the floor, transport it to a given place, and then raise it to such a height as is necessary for stacking or tiering, as in a storeroom or freight car. Figure 47 shows such a truck in operation. The time required for raising and lowering the load is short and this type of lift truck will handle a 4,000- to 6,000-lb. load with safety. There are many modifications of the standard

FIG. 47.—High-lift electric truck. Capacity, 4,000 lb. Lifting range, 5 ft. (*Courtesy of The Yale and Towne Manufacturing Company.*)

FIG. 48.—Tin-plate truck, two-wheel drive; four-wheel steer, capacity, 3,000 lb. (*Courtesy of The Baker-Rauling Company.*)

lift truck or tiering machine, and by special designed attachments these trucks may be used for handling heavy objects of almost any size or shape, as rolls of paper or bundles of sheet iron. Figure 48 shows such a truck, made to pick up, move, and stack sheet tin plate, loose or in bundles.

The Power-platform Truck.

The power-platform truck is commonly used for interior plant movement of materials. This truck handles miscellaneous units of material which can be placed on the platform by hand, chain blocks, hoist, or crane service. By using auxiliary equipment the truck may be converted into a gravity dump for hand-

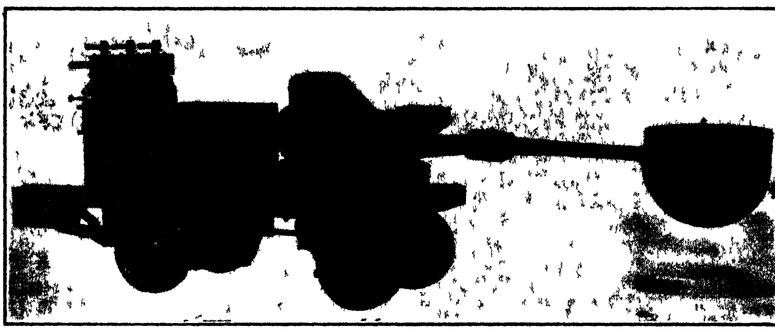


FIG. 49.—Electric-platform truck designed to handle molten glass (*Courtesy of The Baker-Rauling Company*)

ling loose materials or a swing boom crane, and even such devices as special ladles for handling glass have been successfully designed, as shown in Fig. 49. The platform electric truck usually carries the batteries under the platform and consequently has a greater available platform area. The wheels are large, and spring suspension permits effective operation over rough floors, which is not possible with the lift truck.

Tractors.

The tractor is primarily intended for hauling trains of trailers which may be standard or of special design. Tractors may be driven by an electric motor or gasoline motor, but a majority are electrically driven. Tractor-trailer systems are used to best advantage where the length of haul and the material handled is largely of one classification and where the loading, unloading, and

the transportation of the product can be so controlled as to produce a continuous chain of activity.

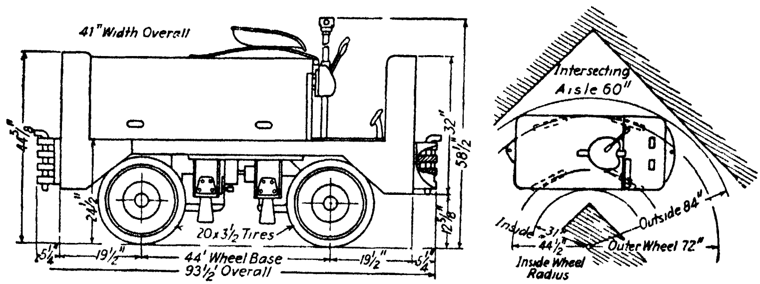


Fig. 50.—Electric tractor.

Conveyors.

Power and gravity conveyors play a very important part in materials-handling today and many of the large factories are designed and laid out with this definitely in mind. E. L. Spray,

Fig. 51.—Roller conveyors greatly facilitate packing operations. Straight-line packing methods are used by The Maytag Company. (*Courtesy of The Maytag Company.*)

works engineer of the Westinghouse Electric and Manufacturing Company, gives the following explanation of their very efficient production and handling methods at the Mansfield plant. Here

they make extended use of the conveyor for the manuf safety switches.

"Straight-line production was made possible by the ment of equipment and storerooms on the two floors so t part proceeded in the most direct manner from operation to operation and through assembling. Elimination of most of the trucking was accomplished by the use of conveyor systems between the different processes.

"Material is received on railroad cars which are run directly into the building. Sheet steel is unloaded by hand, piled on lift-truck platforms, and taken to the various shearing machines, as needed. When the plates have been sheared to the correct sizes for the various types of safety switches, they are stacked on four-wheel platform skids and delivered to the pressroom for the forming operations.

"The press department, which is located on the first floor, supplies parts for a large number of products, such as electric ranges, electric irons, safety switches, etc. . . .

"A safety switch box consists of a 'channel' forming the body of the box, two ends, and a cover. Larger types have a small cover attached to the main cover so that fuses can be replaced without exposing the switch mechanism and endangering the workman who is renewing them. . . .

" . . . Operations on switch-box channels consist of shearing, blanking, punching and trimming, notching and forming. On covers the work consists of shearing, forming the dome, cutting and punching, forming edges, stenciling and piercing for name plate. As far as possible, if the jobs ahead of the various pieces of equipment permit, these operations are done on adjacent machines to coordinate the work.

"Finished parts are individually inspected in the press department. They are then counted and stacked in tote pans to be sent to the storerooms or assembling departments. . . . These small parts are delivered to the inspector in tote pans. They are counted by weighing and then are ready for the storeroom.

"A booster conveyor carries the tote pans of safety-switch parts from the pressroom up to the storerooms on the second floor in an adjacent part of the building. This conveyor enters at 1 in Fig. 52. It is at ceiling height. Boxes of parts for certain types of switches are turned aside by a deflector at 2, are lowered to bench height by spiral 3, and pass down gravity roller con-

veyor 4, from which they are removed and placed on the storage shelving at 5.

"Other switch-box parts are allowed to proceed along the main conveyor until they reach deflector 6, which shunts them to spiral 7 and down to gravity roller conveyor 8. From this they are removed and placed in storage at 9.

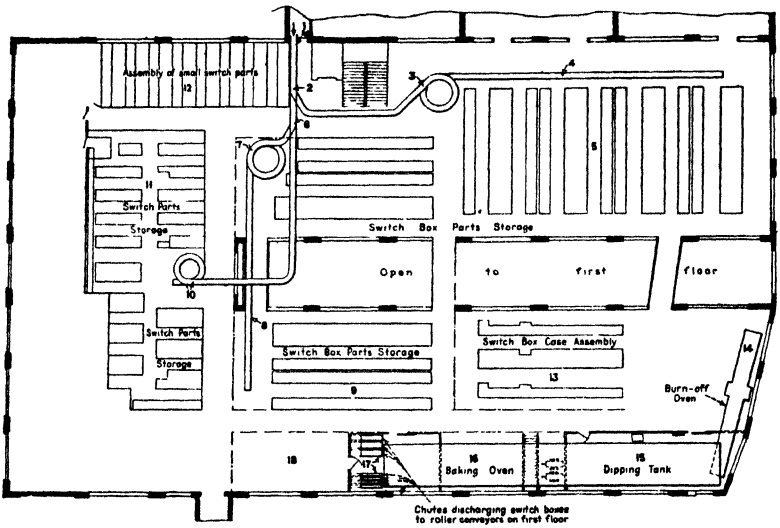


FIG. 52.—Layout of conveyors, storerooms and manufacturing equipment on second floor.

1. Conveyor from press room.
2. Deflector for parts going to 5.
3. Spiral conveyor.
4. Conveyor leading to 5.
5. Storage shelving for switch-box parts.
6. Deflector for parts going to 9.
7. Spiral conveyor.
8. Conveyor leading to 9.
9. Storage shelving for switch-box parts.
10. Conveyor and spiral leading to 11.
11. Storage shelving for small parts of switches.
12. Assembly department for subassemblies
13. Switch-box assembly.
14. Burn-off oven to remove oil from switch boxes.
15. Dipping tank for painting boxes.
16. Drying oven to bake paint.
17. Chutes leading to seven conveyors on first floor.
18. "Cushion" storage of painted boxes.

"Safety-switch mechanism parts are sent along the main conveyor to spiral 10, down which they descend for storage at 11. Tote pans with tapered sides are used for the transportation of parts. In the storeroom two sizes of straight-sided boxes are employed.

"Safety-switch mechanism parts are kept in storeroom 11 until needed for assembling. They are then requisitioned out and to go the benches at 12, where subassemblies are made. The

subassemblies are sent back to storeroom 11 and retained until required by the main assembling departments.

"Rough cast parts for safety switches come in from the foundry at Cleveland. They arrive in cars on the first floor and are sent to the machine department on the second floor, where the finishing operations are performed. The castings are then trucked to the storeroom, later to be delivered to the assembling departments. The volume of such parts is not large and consequently conveyor equipment is not needed.

"Most of the assembling work on safety-switch boxes is done on the second floor on the benches at 13. . . .

"Assembled boxes are delivered to the burn-off oven 14 at the end of the department. The boxes are passed through this oven to remove from the metal oil and grease collected in manufacturing operations. A conveyor carries the boxes through the oven. When they come out they are cooled and then are ready for painting.

"The switch boxes are painted by dipping them in a japanning solution at 15. This solution is heated by steam coils under thermostatic control and is maintained at a definite temperature. It is periodically cleaned by passing through a filter. The boxes coming from the burn-off oven are hung on a chain conveyor which lowers them beneath the surface of the japanning solution. They are then carried over a drip pan and into an electric baking oven 16. This oven was made at the plant and is of A-shape. Temperatures from six points in the oven are registered by means of thermocouple action on the chart of a recording pyrometer. Air is circulated through the oven by means of a motor-driven fan, after first passing through an air cleaner. . . .

"As the boxes leave the oven they are inspected while still on the conveyor and are retouched where necessary by means of a paint spray. Then they are taken from the conveyor and placed, according to size and style, in one of seven chutes 17 discharging to conveyors on the floor below. If any of the chutes are full, the boxes are stacked on trucks and moved into an adjacent temporary storeroom 18 as a cushion supply to take care of either congestion or slack in the production processes.

"On the first floor of the plant are seven assembly lines for safety switches. These assembly lines are supplied with the switch boxes by means of gravity roller conveyors leading from the chutes on the second floor (17 in Fig. 52 and 19 in Fig. 53).

The conveyors come into the department at ceiling height and discharge on the assembly conveyors at bench height.

"Switch mechanisms are assembled on insulated bases, or panels, of porcelain, composition, or slate. This work is done

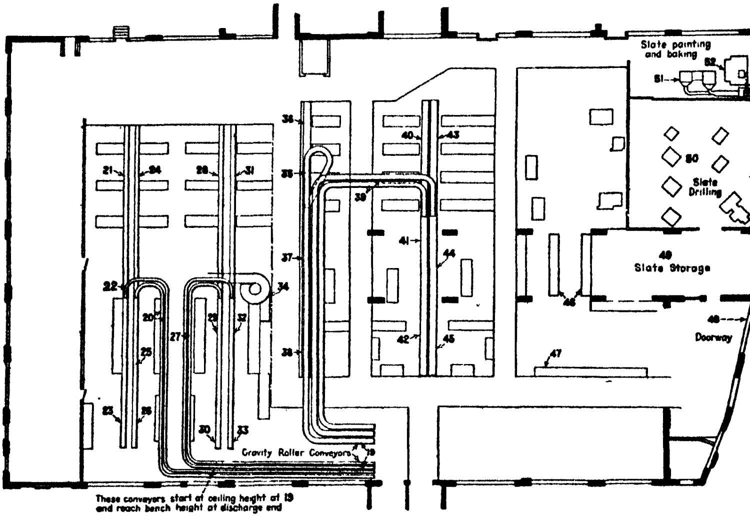


FIG. 53.—Layout of conveyors and equipment on first floor, where panel and switch box assembling are completed.

19. Conveyors from 17, second floor.
20. Conveyors supplying switch boxes to 22 and 25.
21. Conveyor carrying assembled porcelain switch panels to 22.
22. Assembly of panels in switch boxes.
23. Inspection and packing.
24. Conveyor carrying assembled snap switch panels to 25.
25. Assembly of snap switch panels in boxes.
26. Inspection and packing.
27. Conveyors carrying switch boxes to 29. and 32.
28. Conveyor carrying small assembled slate switch panels to 29.
29. Assembly of panels in switch boxes.
30. Inspection and packing.
31. Conveyor carrying small assembled slate switch panels to 32.
32. Assembly of panels in switch boxes.
33. Inspection and packing.
34. Spiral for small parts from storeroom 11 (Fig. 52).
35. Conveyor carrying switch boxes to 37.
36. Conveyor carrying assembled slate switch panels to 37.
37. Assembly of panels in switch boxes.
38. Inspection and packing.
39. Conveyors carrying switch boxes to 41 and 44.
40. Conveyor carrying assembled slate switch panels to 41.
41. Assembly of panels in switch boxes.
42. Inspection and packing.
43. Conveyor carrying assembled slate switch panels to 44.
44. Assembly of panels in switch boxes.
45. Inspection and packing.
46. Assembly of large-size and special switch boxes.
47. Assembly of large-size panels in switch boxes.
48. Doorway through which slate is unloaded from cars.
49. Slate panel storage.
50. Machine room for slate panels.
51. Paint spray booths for slate panels.
52. Baking ovens for slate panels.

on the benches at the upper end of the department (top of Fig. 53). Subassemblies for the switches come down from the storeroom 11 (Fig. 52) by means of a conveyor and spiral 34 delivering them to the final assembling department. When the mechanisms have been assembled at the various benches they are put on roller conveyors 21, 24, 28, 31, 40, and 43, which carry them down

the department to the respective assembly conveyors 22, 25, 29, 32, 37, 41, and 44. Here the mechanisms are attached in the respective types of switch boxes fed to the various points of assembly by conveyors 20, 27, 35, and 39.

"When this final assembly work has been performed, the completed safety switches are moved down the conveyors to the respective stations for inspection (23, 26, 30, 33, 38, 42, and 45). After they are examined and tested for correct action they are packed in cartons and carried to the storage warehouse in an adjacent building by a conveyor, not shown in the photographs."[1]

Railroad Sidings and Trackage Layouts.

The railroad sidings are a part of the general layout of a plant and belong to the company on whose land they are built, although

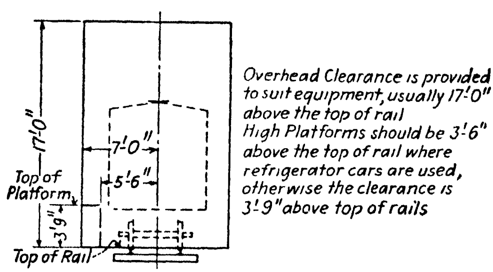


FIG. 54.—Clearance diagram for box car, Illinois Central Railroad Standard.

they may have been constructed and arranged according to the specifications of the railroad company to which they are connected. Each company has its own regulations with regard to sidings, but some general data can be given. It is desirable to provide for car storage as well as for loading and unloading of the car itself. For allowing space for this, 50 ft. per car will be required.

Unless the plant has its own shifting engines it must provide sufficient siding and loading and unloading space so that cars can be shifted by the engines of the railroad company. As a rule, they do not give such service oftener than once a day. Since the sidings will be a permanent part of the plant layout, they should be built so that they will need little or no attention, and some thought should be given to possible additions or rearrangements in the case of expansion of the plant itself.

[1] SPRAY, E. L., Better Methods Cut Handling Costs 50 per cent, *Mfg. Ind.*, vol. 13, No. 2, p. 101, February, 1927.

It is often desirable to have scales built under a section of the track, and when this is done care should be used to see that the scales are of sufficient capacity to weigh cars of maximum loadings. The scales should be located at the most convenient place, this often being near the entrance of the siding into the company yards.

Data on Railroad Yards and Trackage Layouts.

1. Standard gage of railway track is the distance between the inner sides of the rail heads and is 4 ft. 8½ in. The gage on sharp curves is widened ½ to 1 in.
2. The average length of a box car is 42 ft.
3. The maximum weight of a loaded freight car is 210,000 lb.
4. Dimensions of ordinary cross-tie are 8 ft. long, 8 in. wide, and 6 in. deep.
5. The distance between centers of main-line tracks is 13 ft.
6. The grade of tracks should be as low as possible and never exceed 5 per cent. When over 2 per cent, vertical curve should be used.
7. Tracks inside buildings should have the top of rail even with the floor.
8. Ties are spaced 20 to 24 in. on centers.
9. Crossings are built of plank or other material brought to within ½ in. of the top of the rail.
10. Track doors for industrial buildings should be 12 to 14 ft. wide and at least 15 ft. high.

Formulas for Computing Economies of Labor-saving Equipment.

Most materials-handling problems are of such nature as to require individual consideration. After a survey and analysis of the particular problem, the probable "best" methods will likely be narrowed down to two or three. It then becomes necessary to make detailed estimates of total investment costs as well as operating costs of each of the methods and in this manner determine the kind of equipment that should be installed to give the most economical results.

The materials-handling division of the American Society of Mechanical Engineers has developed the following formula[1] which will aid in solving problems suggested above:

[1] Formulas for Computing Economies of Labor-saving Equipment. *Trans. A.S.M.E.*, vol. 47, p. 525, 1925.

Let

Debit items......

A = percentage allowance on investment.
B = percentage allowance to provide for insurance, taxes, etc.
C = percentage allowance to provide for upkeep.
D = percentage allowance to provide for depreciation and obsolescence.
E = yearly cost of power, supplies, and other items which are consumed, total in dollars.

Credit items.....

S = yearly saving in direct cost of labor, in dollars.
T_a = yearly saving in labor burden, in dollars.
T_b = yearly fixed charges on mechanical equipment employed as a standard of comparison or which will be displaced, in dollars.
U = yearly saving or earning through increased production, in dollars.

Other items......

X = percentage of year during which equipment will be employed.
I = initial cost of mechanical equipment, in dollars.
K = unamortized value of equipment displaced, less its resale or scrap value, in dollars.

Results..........

Z = maximum investment in dollars justified by the above consideration.
Y = yearly cost to maintain mechanical equipment ready for operation, in dollars.
V = yearly profit from operation of mechanical equipment, in dollars.
P = percentage of annual profit on investment, including interest charges.
H = number of years required to pay for installation.

$$(1)\quad Z = \left[\frac{(S + T_a + U - E)X + T_b}{A + B + C + D}\right] - K,$$

$$(2)\quad Y = I(A + B + C + D),$$

$$(3)\quad V = [(S + T_a + U - E)X + T_b] - [Y + (KA)],$$

in which

$$(4)\quad P = \frac{V}{I} + A,$$

$$(5)\quad H = \frac{100 \text{ per cent}}{P + D}.$$

Believing that handling machinery, even if left idle a large part of the year, would probably require, under most conditions, approximately the same repair through deterioration as though in use, the committee makes no deduction for such lack of use in

TABLE Vc.—CONDENSED STATEMENT OF FACTORS IN MATERIALS-HANDLING FORMULAS

Item	Total cost including installation and auxiliary equipment	Annual labor saving	Per cent on investment	Per cent on insurance	Per cent for maintenance	Per cent for depreciation	Cost of power	Overhead annual saving	Replaced equipment fixed charges	Value of increased production	New equipment fixed charges	Unamortized value less resale value	Maximum investment to return simple interest on investment	Yearly profit from operation	Yearly profit in per cent investment	Years for complete amortization out of profits
	I	S	A	B	C	D	E	T_a	T_b	U	Y	K	Z	V	P	H
Coal- and ash-handling system in heating plant	$ 1,618	$ 600	6	2	10	10	$ 40	0	0	0	$ 453	0	$ 1,928	$ 107	12.61	4.42
Battery truck in wire mill	2,143	3,200	6	2	20	17	70	0	0	0	964	0	6,955	2,166	106.98	0.807
Battery truck in rubber mill	5,600	2,400	6	2	20	17	100	0	0	0	2,520	0	5,111	−220	2.07	5.24
Finished-stock room to shipping-room conveyor	1,450	2,400	6	2	8	10	50	0	0	0	377	0	9,038	1,973	142.07	0.657
Rubber finish to stock-room conveyor	1,500	1,800 Estimated	6	2	5	10	0	0	0	0	345	0	7,826	1,455	103.00	0.885
Label-department conveyor	2,000	4,000 Estimated	6	2	8	10	40	0	0	0	520	0	15,231	3,440	183.00	0.518
Stock-room to shipping-room conveyor	2,200	3,000	6	2	5	10	0	0	0	0	506	0	13,044	2,494	119.66	0.771
Railroad cars to stores and finished stock to cars	3,100	2,400	6	2	10	10	100	0	0	0	868	0	8,846	1,432	52.19	1.61
Totals	$19,611	$19,800	6	2	12.63	12.76	$400	0	0	0	$6,553	0	$67,979	$12,847	71.51	1.187

NOTE.—Factor X was taken at 100 per cent of full normal-time operation

the estimated cost of upkeep C. If greater accuracy be considered necessary, use C multiplied by X in place of C in the formulas.[1]

Table Vc shows how the above formula has been applied to some actual handling problems at the Belden Manufacturing Company.[2] The total cost of these systems installed was $19,611. The labor saving was $19,800, or 1.6 per cent of the pay roll.

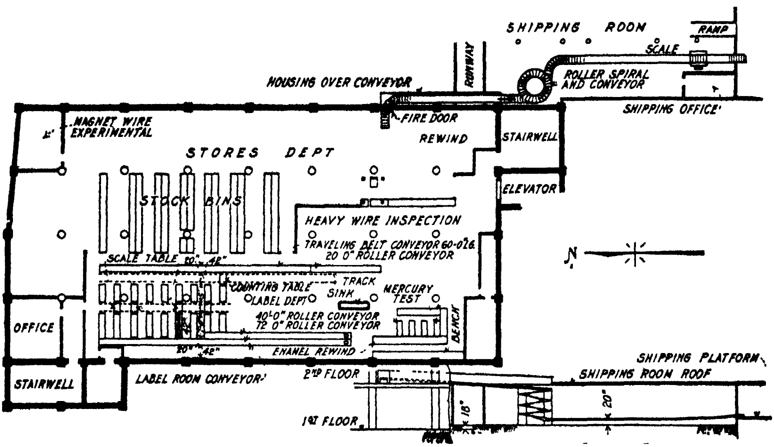


FIG. 55—Layout of conveyor systems for label department and stock room to shipping department.

Power to operate the systems costs $400 a year; fixed charges on installed costs amount to $6,950 annually. The yearly profit on the investment resulting from the operation of this equipment is $12,847, or 71.51 per cent. The equipment completely pays for itself out of profits in 1 year, 2½ months as a total investment, although individual installations require as much as 5¼ years for complete amortization out of their individual earnings.

[1] See ALFORD, L. P., ed., "Management's Handbook," p. 752, for detailed solution of sample problems.

[2] COES, H. V., Industry's Annual Tax for Materials Handling and Suggestions for Its Elimination, *Mech. Eng.*, vol. 48, No. 11a, p. 1255, November, 1926.

CHAPTER V

INDUSTRIAL LIGHTING

DAYLIGHTING

Factory lighting should be studied from two angles: First, the building must be designed for sufficient natural light, and then provision should be made for adequate artificial illumination. The artificial lighting should be so arranged that it will blend with and supplement the natural lighting, for there is a considerable period of the year when both natural and artificial light will be needed in any given floor area. Considerable attention has been devoted to the design of artificial illumination, but until recently relatively little study has been directed toward the solution of natural lighting problems. There are a number of reasons which no doubt account for this. The structural design of the building and the arrangement of the equipment inside the plant are often given first consideration, and in many cases proper natural lighting has not been provided.

Difficulties Involved in Natural Lighting.

However, when serious thought is given to the question of natural lighting one of the first obstacles encountered is the wide variation in the intensity of natural illumination produced by the sun (on a horizontal plane) throughout the day. The intensity may reach a maximum of 10,000 to 12,000 ft.-candles at noon with a clear sky.

Figure 56 shows the results of a large number of daylight illumination measurements made by the U. S. Weather Bureau. The curves[1] show the order of natural illumination available throughout the year in the latitude of Boston and Chicago for cloudy and clear skies, the illumination being expressed in terms of foot-candles on an out-of-door unobstructed horizontal surface.

Figure 57 shows the influence of clouds upon illumination and sky brightness. This is a continuous record of daylight taken

[1] *Monthly Weather Rev.*, vol. 47, pp. 769–793, November, 1919; also vol. 49, pp. 481–488, September, 1921.

at Washington, D. C., on a particularly cloudy day in midsummer. Because of the wide fluctuations in sky brightness from hour to hour during the day and from month to month

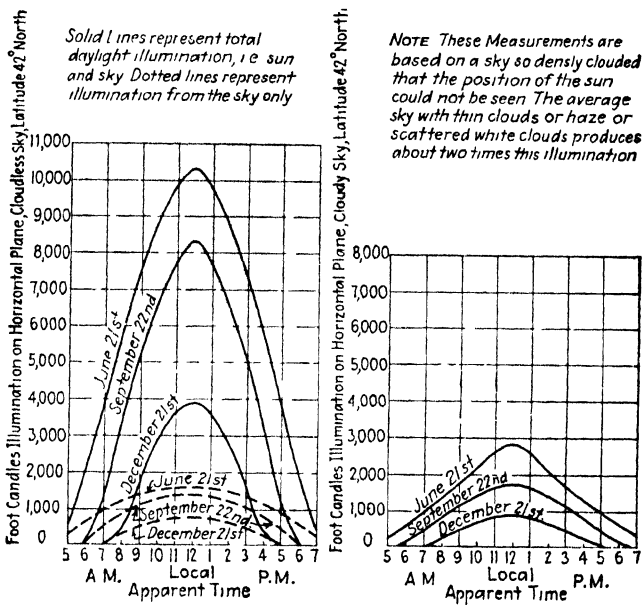


FIG. 56—Showing diurnal variation in daylight for clear and cloudy skies throughout the year

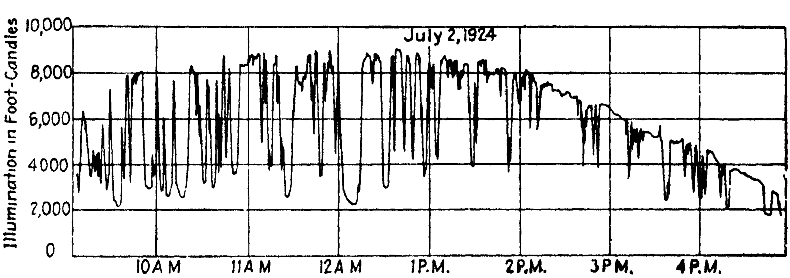


FIG. 57—Part of the daylight record for July 2, 1924, made in the office of industrial hygiene and sanitation of the U. S. Public Health Service at Washington, D. C., showing the rapid variation in illumination that may occur on a day in summer in Washington.

during the year, it is apparent at once that the intensity of illumination supplied by the sun is not constant but a widely varying quantity. Other equally variable quantities that affect proper daylighting are the transmission of light through the

different kinds of glass when clean and dirty and the reflection factors of neighboring buildings and other exterior surroundings. Despite these and other variable factors, the problem of providing adequate natural light for a building can be solved.

The Relation of Building Design to Natural Lighting.

The relation of building design to natural lighting will be treated in three parts: The first part will include data and rules that are now generally used in designing and proportioning walls, windows, skylights, and other elements of a building. The second will explain briefly the use of scale models in predicting daylight intensities for any point within a proposed building; and the third will show the mathematical treatment of the same problem.

Data for Building Design and Daylighting. Single-story Buildings.

Extensive investigations on daylighting have been carried on by the Detroit Steel Products Co. under the supervision of their chief engineer, W. C. Randall, and the results of this work have been published in the *Transactions of the Illuminating Engineering Society*. The following material has been taken from their findings:

1. With side-wall windows on one side only, the working space is limited to a distance back from the window of approximately three times the height of the window if the windows are kept relatively clean. When the windows are washed not oftener than once every 6 months, this distance will be reduced to two times the height.

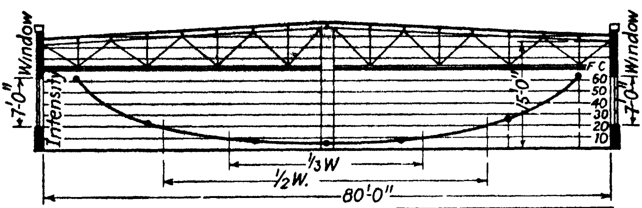
2. The upper part of the window is the part that throws the light back into the building, the point of minimum intensity of illumination. The increase in the minimum intensity is greater than the increase in height of the window.

3. When a building is lighted from the side wall only, the area of the windows should be not less than 30 per cent of the floor area.

4. The maximum light intensity in a building increases in a lesser proportion than the increase in the window area. The minimum intensity will, in general, increase by a much greater percentage than the increase in the window area. For good

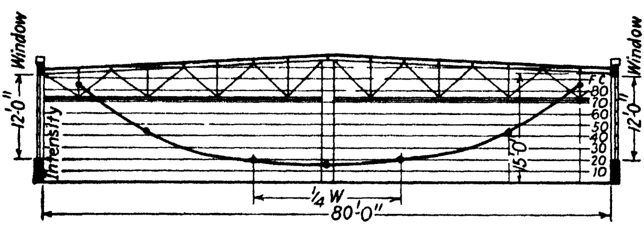
lighting the ratio of high to low values should not be greater than three to one, a ratio that is usually not bettered in artificial lighting.

5. On the average, vertical windows lose 50 per cent of their efficiency through a 6 months' accumulation of dirt, so that washing these windows will double their light-emitting qualities. Windows sloping 30 deg. lose 75 per cent of their efficiency through a 6 months' collection of dirt. The accumulation of



Ft Back	5	15	30	40
FC Clean	62	24	9	8

FIG. 58.—Distribution of daylighting from windows 7 ft. high, in two opposite side walls.



Ft Back	5	15	30	40
FC Clean	82	42	20	18

FIG. 59.—Distribution of daylighting from windows 12 ft. high, in two opposite side walls.

dirt on a window over a given length of time is about 75 per cent on the inside and 25 per cent on the outside.[1]

Single-story Buildings with Monitors.

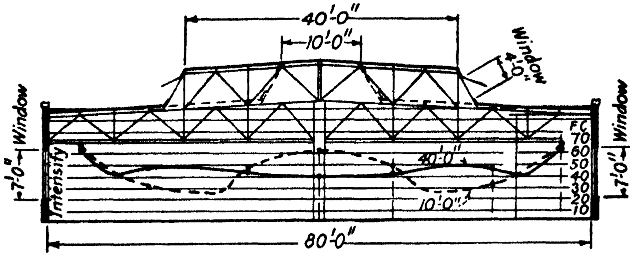
1. Where there is a monitor, the total glass area in it and the side-wall windows should be about 30 per cent of the floor area; this percentage could be reduced to 25 per cent if the window-washing intervals were not longer than 4 months.

2. The best results can be obtained with the width of the monitor equal to one-half the width of the building, or floor space to

[1] RANDALL, W. C., and A. J. MARTIN, Making Your Windows Deliver Daylight, *Trans. I.E.S.*, vol. 22, No. 3, p. 239, March, 1927.

be lighted by the monitor, in the case of building with more than one monitor. Narrow monitors should be avoided if possible (see Fig. 60).

3. As the windows of a monitor slope from the vertical, more daylight enters the building. However, there is not much difference in the results from vertical and sloping windows in the monitor when dirt accumulation is considered.[1]



Span	40'0"	10'0"
Max F.C.	65	67
Min. F.C	41	25

Fig. 60.—Effect of span of monitor on distribution of daylighting, sloping windows being used.

Single-story Buildings with Saw-tooth Roof.

A large percentage of single-story buildings are lighted by means of "saw teeth" in the roof. It is desirable to orient the saw-tooth windows so that the direct rays of the sun are excluded, that is, with these windows facing north. There is no limit to the size of a single-story building that can be lighted by the use of saw-tooth construction. Mr. Randall gives the following rules[2] for the design of saw-tooth roofs:

1. For practically all of the United States, the windows should be placed on the vertical, if the sunlight is to be excluded during the average working day.

2. For the lower latitudes of the United States, where the exclusion of sunlight might be more of a factor at least, the windows should be placed on the vertical, and probably some additional provision made to exclude the sunlight.

3. Increase in the span decreases the minimum foot-candles almost in proportion as the span increases, has little effect on the

[1] Randall, W. C., Designing for Daylight, *Trans. I.E.S.*, vol. 22, No. 6, p. 607, July, 1927.

[2] Randall, W. C., Saw-tooth Design—Its Effect on Natural Illumination, *Trans. I.E.S.*, vol. 21, No. 3, p. 241 March, 1926.

maximum foot-candles, and, of necessity, the ratio of maximum to minimum increases as the span increases.

4. With clean glass, sloping the windows increases both the maximum and minimum foot-candles, but after correction for dirt accumulation for average periods between cleaning, this advantage disappears, and, if anything, the advantage is in favor of vertical windows (see Fig. 61).

5. Increase in the height of windows will, in general, increase the maximum foot-candle intensity on the working plane in proportion to the increase of height. There is a slightly greater proportionate increase in the minimum foot-candles.

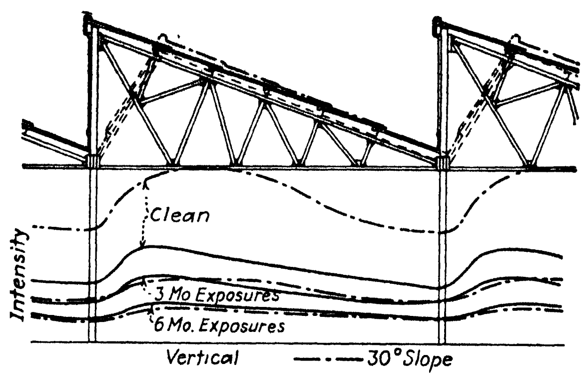


FIG. 61.—Characteristic distributions of daylight in saw-tooth building, with windows vertical and 30 deg. from vertical, showing effect of dirt accumulations on glass.

6. Painting the underside of the roof and thereby obtaining a high reflection coefficient produces relatively small results in so far as natural illumination is concerned.

7. It is desirable to use either clear sheet glass or rough wire glass, rather than ribbed glass, due to the higher transmission factors and the greater ease of keeping clean.

8. As the height of the sill of the window is increased, the maximum intensity on the working plane is decreased, and within reasonable limits the minimum is increased and the uniformity improved.

Multistory Buildings.

The following information is of value in providing natural lighting for multistory buildings:

1. The distance between buildings should at least be equal to the height of the building. Wherever possible, buildings should be constructed as separate units and not connected, as the connections reduce the amount of light on either side of the connection.

2. The width of windows should be at least 80 per cent of the center-to-center distance of supporting columns. It is desirable to make this distance just as great as possible.

3. Windows should extend as close to the ceiling as the design will permit. Where reinforced concrete construction is used, flat slab is more desirable than beam-and-girder construction as far as lighting is concerned.

4. Artificial lighting should parallel daylighting; that is, the lamp circuits should be arranged parallel with the windows so that the lamps on the line of minimum illumination can be turned on first and the others in order as daylight wanes.[1]

5. Where buildings are grouped, the exteriors should have light-colored surfaces in order to reflect the maximum amount of daylight into the adjoining buildings. The interior of the buildings should be finished in a light color, particularly the lower stories. However, it is of greater importance that the outside of the building have a high reflection factor than it is for the inside of the building. If it were recognized that the daylight illumination in the interior of a room located at the bottom of a closed court with light walls could be as much as twenty times as great as if the walls were dark colored, it is quite possible that there would be a much greater use of light-colored materials in courts. Similarly, if it were known that white glazed brick, due to its high light-reflecting value, would give as much as four or five times the daylighting that dark-colored brick would, in the case of buildings facing each other on the street it is quite possible that less dark-colored brick would be used in the exterior walls.[2] The result of some tests made along this line are shown in Figs. 63 and 64. Figure 62 shows the location of the stations and the meaning of the relation C/H referred to in the figures mentioned above.

[1] VOGEL, ANDREW, and others, Daylighting in Multistory Industrial Buildings, *Trans. I.E.S.*, vol. 23, No. 2, p. 129, February, 1928.

[2] RANDALL, W. C., and A. J. MARTIN, The Utilization of Exterior Reflecting Surfaces in Daylighting, *Trans. I.E.S.*, vol. 24, No. 3, p. 301, March, 1929.

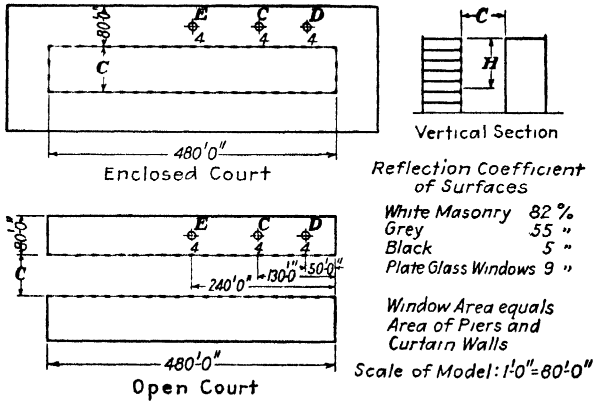


FIG. 62.—Location of stations discussed.

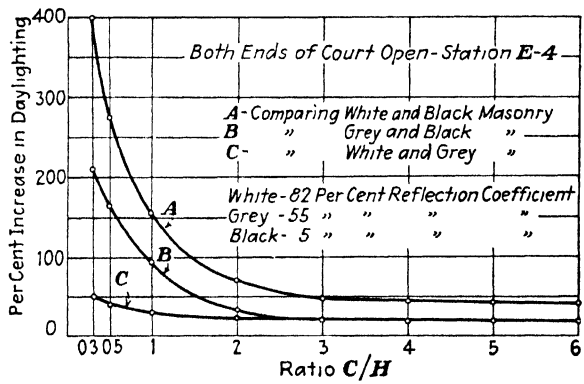


FIG. 63.—The reflection coefficient of the exterior walls has a greater effect at a station near the center of the building with open court.

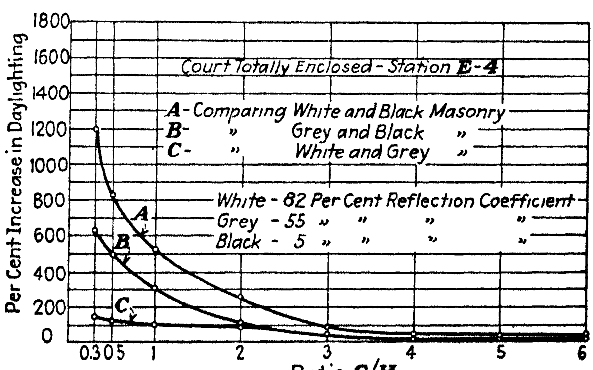


FIG. 64.—The effect of the reflection coefficient of exterior walls on a station at the longitudinal center of the building.

TABLE VI.—REFLECTION COEFFICIENTS OF VARIOUS MATERIALS USED FOR FACING BUILDINGS

Color and material	Surface	Per cent	Color and material	Surface	Per cent
White terra-cotta	Semigloss	81.2	Light blue-gray terra-cotta	Semigloss	41.5
White terra-cotta	Semigloss	80.8	Dark tan terra-cotta	Semigloss	28.2
Cream-white terra-cotta	Semigloss	76.9	Light green terra-cotta	Semigloss	24.8
Cream terra-cotta	Semigloss	74.2	Light chocolate terra-cotta	Rough	21.1
Cream terra-cotta	Semigloss	73.5	Chestnut brown terra-cotta	Semigloss	15.1
Cream terra-cotta	Matte	72.3	Brown terra-cotta	Matte	12.3
Ivory terra-cotta	Semigloss	67.8	Dark clay slate	Matte	6.7
Ivory terra-cotta	Semigloss	67.5	White brick	Glazed	87.3
Pale red-gray	Semigloss	52.4	Ivory brick	Glazed	68.5
Ivory tan	Semigloss	52.3	Buff	Matte	51.1
Ivory tan	Semigloss	49.2	Dark buff brick	Matte	44.2
Light gray	Matte	46.0	Light granite terra-cotta	Glazed	42.4
Reddish buff	Semigloss	45.8	Dark red brick	Glazed	23.4

Data shown above obtained on Keuffel and Esser color analyzer at wavelength $\lambda = 0.60\mu$.

The Use of Scale Models.

Scale models are used to a limited extent as an aid in predicting natural lighting within buildings. Wood or beaver-board models of the proposed building are constructed and an artificial sky is

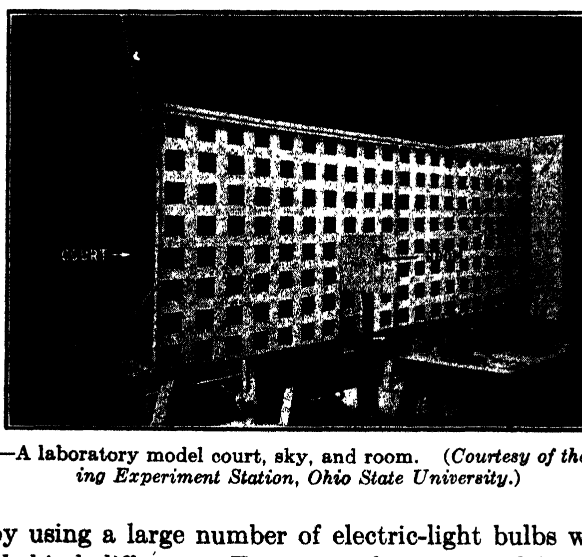


FIG. 65.—A laboratory model court, sky, and room. (*Courtesy of the Engineering Experiment Station, Ohio State University.*)

made by using a large number of electric-light bulbs which are placed behind diffusers. Figure 65 shows a model court of a multistory building in the Engineering Experimental Station

Laboratory at Ohio State University.[1] The sky and the room are also shown. While the normal court of a building is vertical and under a horizontal sky, laboratory conditions require the use of a horizontal court and a vertical sky. This should not affect the results. The scale of the model shown is 1:20.

A series of tests were made at the University of Michigan using scale models of both single- and multistory buildings. The results of these tests were checked against actual readings made in the field on full-size buildings. There was found to be only a very slight percentage of variation between the two.

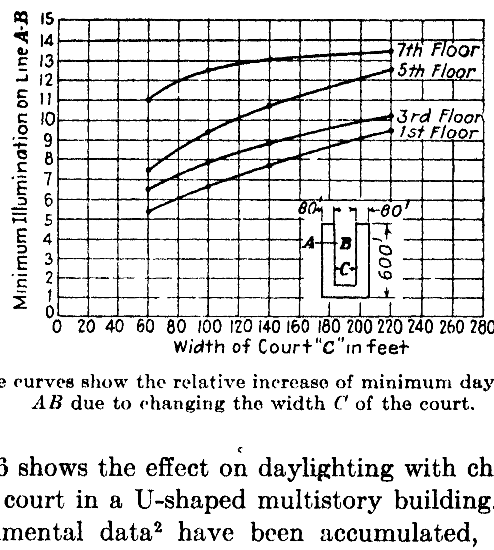


FIG. 66.—The curves show the relative increase of minimum daylighting on line AB due to changing the width C of the court.

Figure 66 shows the effect on daylighting with changes in the width of a court in a U-shaped multistory building. Considerable experimental data[2] have been accumulated, and various sets of curves such as these are now available to aid the engineer and architect in his daylighting problems.

The Use of the Mathematical Method.

Professor H. H. Higbie at the University of Michigan has developed a formula which makes it possible to calculate the intensity of illumination for any point within a building. The process becomes rather involved in many cases, but the results check closely with model readings and with field tests on full-

[1] TANG, K. Y., A Method of Predicting Illumination from Light Courts, *Bull.* 47, Eng. Expt. Sta., Ohio State University.

[2] VOGEL, ANDREW, and others, Daylighting in Multistory Industrial Buildings, *Trans. I.E.S.*, vol. 23, No. 2, p. 136, February, 1928.

sized buildings.[1] Because of lack of space this method will not be explained here.

Tables for Predicting Daylighting for Buildings.[2]

"Table VII shows the foot-candles delivered by any one of 13 Fenestra side-wall window heights (5 ft. 2 in., 6 ft. 10⅜ in., 8 ft. 6¾ in., etc., across the top of the table) to various positions measured from the side walls back toward the center of the building (5, 10, 15 ft., etc., down the left side of the table). The values given are for a cloudy, overcast sky[3] and windows 6 months dirty.

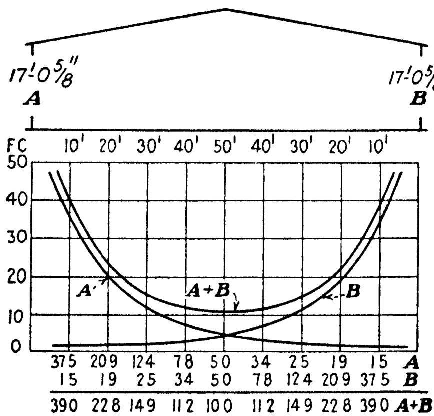


FIG. 67.—Single-story building, windows in side walls only. (*Courtesy of the Detroit Steel Products Company.*)

"Table VIII gives the foot-candles delivered by four of the same windows, set with their sills 15 ft. above the working plane; also 25 ft. above, 35 ft. above, and 45 ft. above.

"From these tables it is possible to figure fairly definitely (for an overcast sky condition) how much daylight can be obtained at any point from any given arrangement of side-wall windows or vertical monitor windows or from combinations of the two.

[1] For a complete development of the formulas and its application see H. H. Higbie, Prediction of Daylight from Vertical Windows, *Trans. I.E.S.*, vol. 20, No. 5, p. 433; *Trans. A.S.M.E.*, vol. 51, No. 9, p. 12; *Bull.* 47, p. 18, Eng. Expt. Sta., Ohio State University.

[2] Industrial Daylighting by the Fenestra Method, p. 14, Detroit Steel Products Company.

[3] An overcast sky gives an average window brightness of approximately 250 cp. per square foot.

TABLE VII.—FOOT-CANDLES FOR VERTICAL WINDOWS AT WORKING PLANE

Feet back from window	3 High 5′ 2″	4 High 6′ 10″	5 High 8′ 6″	6 High 10′ 3″	7 High 11′ 11″	8 High 13′ 7″	9 High 15′ 4″	10 High 17′ 0″	11 High 18′ 9″	12 High 20′ 5″	13 High 22′ 2″	14 High 23′ 11″	15 High 25′ 7″
5	25.0	29.75	34.75	38.5	41.75	44.25	46.5	48.4	50.0	51.5	52.7	53.8	55.0
10	13.1	16.35	20.0	24.25	28.0	31.9	35.0	37.5	40.0	42.0	43.5	45.0	46.5
15	7.5	9.75	12.25	15.5	19.0	21.75	24.25	27.0	29.75	33.0	34.25	36.15	38.0
20	4.8	6.2	8.0	10.25	13.4	16.0	18.0	20.9	23.0	26.0	27.50	29.5	31.5
25	3.3	4.25	5.5	7.25	9.6	11.5	13.75	16.0	18.05	20.5	22.1	23.75	25.75
30	2.35	3.15	4.1	5.5	7.25	8.75	10.5	12.35	14.35	16.5	18.15	19.75	21.25
35	1.75	2.38	3.15	4.2	5.5	6.75	8.1	9.75	11.5	13.25	14.7	16.0	17.5
40	1.36	1.83	2.43	3.25	4.4	5.5	6.5	7.8	9.2	10.6	12.05	13.3	14.5
45	1.06	1.45	1.95	2.55	3.5	4.3	5.15	6.35	7.4	8.6	9.6	10.75	12.1
50	0.85	1.15	1.58	2.1	2.8	3.4	4.2	5.0	6.0	7.0	8.0	8.95	10.1
55	0.70	0.95	1.29	1.72	2.28	2.8	3.45	4.15	4.9	5.75	6.6	7.5	8.5
60	0.6	0.79	1.06	1.41	1.88	2.3	2.9	3.4	4.05	4.75	5.55	6.35	7.15
65	0.5	0.67	0.89	1.18	1.57	1.95	2.35	2.87	3.4	4.0	4.62	5.3	6.1
70	0.43	0.57	0.75	1.0	1.35	1.7	2.08	2.5	2.95	3.45	3.95	4.6	5.05
75	0.37	0.49	0.65	0.85	1.17	1.48	1.78	2.15	2.53	2.95	3.45	4.0	4.55
80	0.32	0.43	0.56	0.75	1.02	1.28	1.55	1.88	2.2	2.58	3.05	3.5	4.0
85	0.28	0.38	0.5	0.66	0.9	1.1	1.35	1.65	1.95	2.26	2.63	3.05	3.5
90	0.24	0.34	0.45	0.59	0.79	0.98	1.2	1.45	1.75	2.05	2.43	2.75	3.1
95	0.22	0.3	0.4	0.53	0.7	0.85	1.05	1.25	1.53	1.83	2.13	2.45	2.8
100	0.2	0.27	0.36	0.47	0.65	0.77	0.95	1.15	1.38	1.65	1.9	2.2	2.5
105	0.18	0.25	0.33	0.43	0.6	0.7	0.85	1.05	1.25	1.5	1.75	2.0	2.25
110	0.16	0.22	0.3	0.4	0.56	0.65	0.79	0.95	1.13	1.36	1.6	1.85	2.1
115	0.15	0.2	0.28	0.37	0.53	0.6	0.74	0.8	1.0	1.25	1.45	1.7	1.88
120	0.14	0.19	0.25	0.35	0.49	0.52	0.69	0.75	0.9	1.15	1.3	1.56	1.7
125	0.13	0.18	0.24	0.33	0.47	0.50	0.65	0.72	0.85	1.05	1.2	1.4	1.55
130	0.12	0.16	0.23	0.32	0.44	0.5	0.62	0.7	0.8	0.98	1.1	1.25	1.41
135	0.11	0.15	0.21	0.3	0.42	0.49	0.59	0.68	0.78	0.91	1.0	1.15	1.3
140	0.1	0.14	0.2	0.29	0.4	0.48	0.57	0.65	0.75	0.85	0.95	1.06	1.2

All glass 20 in. high. All values figured for overcast sky and 6 months' dirt.

Courtesy of the Detroit Steel Products Co.

They are especially convenient in evaluating any particular fenestration and comparing it with other designs. For window heights and sill heights not shown, interpolation is usually considered accurate enough.

"Suppose you have a building 100 ft. wide to be daylighted from the side walls only and you want to know how high to make the windows so that you will have at least 10 ft.-candles in the center with the windows dirty and the sky overcast.

"Turn to Table VII and run down the left-hand column until you reach 50 ft., which represents the center of your 100-ft.

building. Move across to the right until you reach 5 ft.-candles. This intensity will be doubled because the center of the building will be equally lighted from windows on both sides; 5 ft.-candles doubled equals 10 ft.-candles (the minimum requisite). Move up to the top of the column in which 5 ft.-candles appears and you will find at the top 17 ft., which is the necessary height of your windows. Your building and your light curve (see figures under 17 ft., Table VII) will look like those shown in Fig. 67.

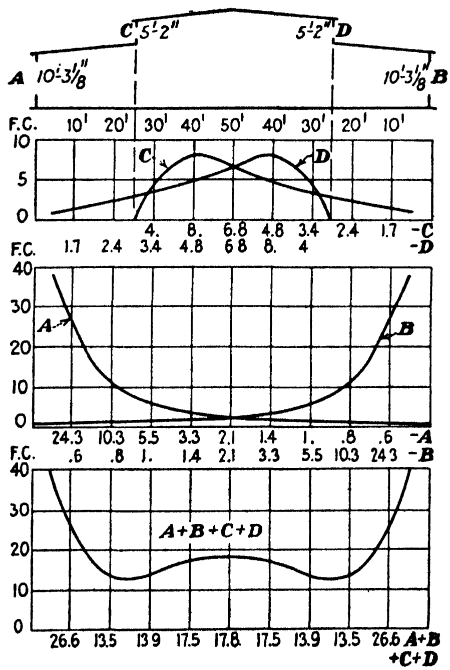


Fig. 68.—Single-story building with 50-ft. wide monitor, windows in side walls and monitor. (*Courtesy of the Detroit Steel Products Company.*)

"But 17-ft. high windows are beyond standard size—would require horizontal structural mullions or other types of wall construction. It might be better to reduce the height of the side-wall windows to 10 ft. 3 in. and install a 50-ft. wide monitor with 5 ft. 2 in. windows on the roof. This would provide 30 ft. 10 in. total height of all four windows as compared to 100-ft. floor width or window area 30 per cent of floor area.

"Your building and its daylight curve will look like the diagram in Fig. 68.

TABLE VIII.—FOOT-CANDLES FOR VERTICAL WINDOWS ABOVE THE WORKING PLANE

Feet back from window	15 ft. above working plane					25 ft. above working plane					35 ft. above working plane					45 ft. above working plane				
	Window heights					Window heights					Window heights					Window heights				
	3′6″	5′2″	6′10″	8′6″	10′3″	3′6″	5′2″	6′10″	8′6″	10′3″	3′6″	5′2″	6′10″	8′6″	10′3″	3′6″	5′2″	6′10″	8′6″	10′3″
5	3.0	4.0	5.1	6.0	6.65	1.15	1.5	1.8	2.1	2.5	0.6	0.85	1.1	1.35	1.6	0.43	0.85	1.4	1.95	2.9
10	5.8	7.4	9.8	11.2	12.0	2.2	3.0	3.55	4.3	4.7	1.25	1.85	2.25	2.85	3.6	1.2	1.7	2.4	3.25	4.15
15	6.6	8.0	10.6	12.8	13.8	2.95	4.4	5.15	6.5	7.1	1.9	2.7	3.3	4.3	5.2	1.7	2.45	3.3	4.05	5.1
20	6.0	7.65	9.8	12.05	13.6	3.5	5.1	6.25	7.75	8.95	2.38	3.3	4.0	5.4	6.6	2.25	3.2	4.0	4.75	5.75
25	5.1	6.8	8.5	10.6	12.2	3.8	5.2	6.6	8.3	9.75	2.73	3.6	4.5	5.9	7.25	2.65	3.8	4.55	5.35	6.25
30	4.3	5.8	7.45	9.2	10.65	3.6	5.0	6.05	8.35	10.0	2.85	3.7	4.6	6.0	7.5	2.85	4.15	4.9	5.75	6.55
35	3.6	4.8	6.35	7.8	9.05	3.4	4.6	6.15	7.75	9.15	2.7	3.55	4.5	5.9	7.45	2.75	3.95	4.85	5.65	6.4
40	3.05	4.0	5.4	6.6	7.8	3.1	4.15	5.5	6.95	8.1	2.45	3.35	4.3	5.75	7.1	2.55	3.7	4.6	5.45	6.15
45	2.5	3.4	4.45	5.5	6.55	2.8	3.7	4.9	6.2	7.25	2.25	3.05	4.0	5.3	6.8	2.35	3.45	4.35	5.2	5.85
50	2.05	2.8	3.7	4.65	5.6	2.55	3.25	4.35	5.5	6.5	2.08	2.8	3.65	4.9	6.4	2.15	3.15	4.0	4.9	5.5
55	1.65	2.4	3.0	3.85	4.75	2.25	2.9	3.85	4.9	5.8	1.9	2.55	3.3	4.45	5.85	2.0	2.85	3.7	4.5	5.25
60	1.25	2.0	2.5	3.25	4.0	2.0	2.55	3.4	4.35	5.15	1.73	2.3	3.0	4.05	5.4	1.85	2.6	3.45	4.15	4.9
65	1.1	1.65	2.1	2.75	3.4	1.75	2.3	3.05	3.85	4.55	1.55	2.1	2.7	3.7	4.8	1.65	2.35	3.15	3.9	4.6
70	0.9	1.4	1.8	2.4	2.95	1.5	2.05	2.7	3.35	4.0	1.4	1.9	2.4	3.35	4.25	1.5	2.15	2.9	3.6	4.3
75	0.75	1.15	1.5	2.05	2.5	1.35	1.85	2.4	3.0	3.5	1.25	1.75	2.18	3.0	3.85	1.35	1.95	2.65	3.35	4.05
80	0.6	1.0	1.3	1.8	2.2	1.2	1.6	2.15	2.65	3.1	1.15	1.58	2.0	2.7	3.45	1.2	1.8	2.4	3.1	3.8
85	0.5	0.85	1.15	1.55	2.0	1.05	1.45	1.9	2.35	2.75	1.06	1.43	1.83	2.4	3.1	1.12	1.65	2.23	2.85	3.55
90	0.45	0.75	1.0	1.35	1.75	0.9	1.25	1.65	2.05	2.45	1.0	1.3	1.68	2.2	2.75	1.03	1.5	2.08	2.65	3.3
95	0.43	0.6	0.9	1.2	1.55	0.8	1.1	1.45	1.8	2.2	0.93	1.2	1.53	2.0	2.5	0.95	1.38	1.95	2.45	3.05
100	0.4	0.55	0.8	1.08	1.4	0.65	0.9	1.2	1.5	1.95	0.9	1.13	1.4	1.83	2.33	0.88	1.25	1.85	2.3	2.85
105	0.35	0.5	0.7	0.9	1.25	0.5	0.75	1.0	1.35	1.75	0.81	1.05	1.3	1.68	2.1	0.8	1.18	1.7	2.15	2.65
110	0.3	0.45	0.55	0.8	1.1	0.4	0.6	0.85	1.16	1.55	0.76	1.0	1.24	1.55	1.98	0.75	1.1	1.58	2.05	2.98
115	0.28	0.39	0.54	0.7	0.98	0.37	0.54	0.73	1.02	1.35	0.73	0.96	1.18	1.45	1.85	0.7	1.03	1.45	1.99	2.3
120	0.25	0.36	0.48	0.65	0.87	0.32	0.46	0.63	0.89	1.2	0.69	0.92	1.14	1.38	1.73	0.67	0.97	1.4	1.83	2.15
125	0.23	0.32	0.43	0.55	0.78	0.27	0.39	0.55	0.76	1.1	0.67	0.88	1.09	1.3	1.6	0.64	0.92	1.3	1.73	2.08
130	0.21	0.29	0.39	0.5	0.7	0.24	0.35	0.47	0.67	0.98	0.64	0.85	1.05	1.25	1.52	0.6	0.87	1.18	1.61	1.93
135	0.2	0.27	0.35	0.45	0.63	0.21	0.3	0.41	0.58	0.86	0.62	0.82	1.02	1.2	1.43	0.59	0.82	1.1	1.53	1.84
140	0.19	0.25	0.32	0.41	0.58	0.19	0.27	0.37	0.51	0.76	0.6	0.8	1.0	1.19	1.36	0.57	0.79	1.05	1.45	1.75

All glass 20 in. high. 6 ft. 10 in., four panes high. All values figured for an overcast sky, 6 months' collection of dirt.
3 ft. 6 in., two panes high. 8 ft. 6 in., five panes high.
5 ft. 2 in., three panes high. 10 ft. 3 in., six panes high.

Courtesy of the Detroit Steel Products Co.

"The curves for windows *A* and *B* are taken from Table VII as before, except that the figures are found in the column headed 10 ft. 3 in.

"The sill of the windows in the monitor will be approximately 15 ft. above the working plane. Therefore, turn to Table VIII and under the heading 15 ft. above working plane find the dimension 5 ft. 2 in. (window height). From the figures in this column plot the daylighting curve for monitor windows *C* and *D*.

"Total the light intensities of all four curves and you will have the total illumination across the width of your building. The minimum illumination is 13.5 ft.-candles, which occurs on either side of the building 20 ft. back from the side walls. The maximum illumination is 39 ft.-candles, which occurs 5 ft. back from the side walls. The ratio between maximum and minimum is three to one."

CHAPTER VI

INDUSTRIAL LIGHTING

ARTIFICIAL LIGHTING

During 15 to 20 per cent of the year the factory must have artificial light to supplement or replace the natural illumination. Diffused daylight is the best illuminant known, and so the artificial lighting should approach this as closely as possible.

Advantages of Good Light.

Proper illumination unquestionably speeds up production and brings about greater efficiency in the factory. An exhaustive test was carried on at the Detroit Piston Ring Company, covering a period of 15 months, in which a careful check was made between production and lighting, all other factors being kept as nearly

TABLE IX.—IMPROVEMENT IN PRODUCTION DUE TO BETTER LIGHTING

Industry	Average foot-candles with		Increase in production, per cent
	Old system	New system	
Insulation tape manufacturing	6.8	7.9	13.0
Dress goods weaving	1.9	9.8	25.0
Infants' hosiery mill	6.5	16.7	10.8
Silk hosiery mill	7.2	21.1	15.0
Piston-ring manufacturing	1.2	18.0	25.8
Letter separating dispatching division	3.3	7.6	12.5
Letter separating final sorting division	3.3	5.9	20.0
Electric and gas sad-iron manufacturing	0.7	13.5	12.2
Carbureter assembly	2.1	12.3	12.0
Heavy steel machine shop	3.0	11.5	10.0
Soft metal bearings	4.6	12.7	15.0
Inspecting roller bearings	5.0	20.0	12.5
Semiautomatic buffing brass shell sockets	3.8	11.4	8.5
Jute spinning	0.3	4.8	35.0
Average	3.4	12.1	16.28

constant as possible. The results showed that with proper lighting, production was increased about 25 per cent. Table IX shows similar increases in production that have resulted from better lighting in other industries. Figure 69 shows the relation between the time of perception and the intensity of illumination on the object. The chart clearly shows how the increased illumination will speed up the process of seeing. A longer time is required to perceive an object under poor light than under good light. Spoilage is also decreased and accidents are greatly reduced by having the factory properly lighted.

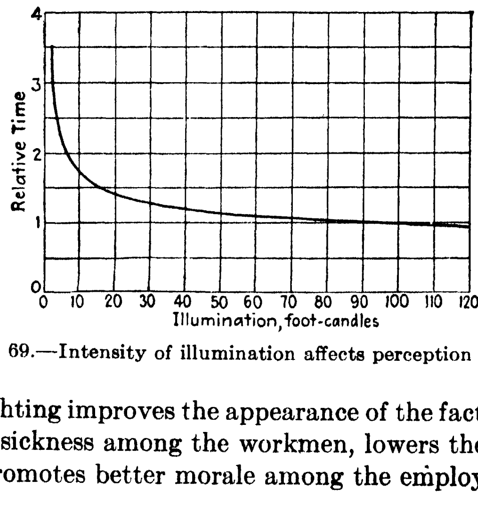


FIG. 69.—Intensity of illumination affects perception time.

Proper lighting improves the appearance of the factory, reduces fatigue and sickness among the workmen, lowers the labor turnover, and promotes better morale among the employees.

Characteristics of Good Artificial Light.

A well-lighted room is one which presents a favorable appearance, with no dark corners or heavy shadows present. The light should be diffused uniformly and distributed evenly throughout the whole room. If the sources of light are placed close together and at considerable distance above the plane of work, there is the tendency for the light rays from the different sources to overlap and produce softer shadows. High intensities and exposed sources of light not only produce the deepest shadows but are likely to produce glare.

Glare may be of two kinds: direct and indirect. Direct glare is caused from exposed light sources and causes eye strain and also contracts the pupil of the eye, which decreases the effectiveness of the lighting system. The eye should not come in direct

FIG. 70.—The illumination in this room at the Timken Roller Bearing Company plant averaged about 5 ft -candles.

FIG. 71.—The new lighting system which replaced that shown above provided a maximum of 1? ft-candles under which production increased 12.5 per cent.

line with an exposed light source except at considerable distance, or at least the light source should be at a 30-deg. angle away from the normal line of sight. The proper design of reflectors and lighting units will correct the cause of direct glare. Indirect or reflected glare is perhaps more annoying and tiring to the eye and is at least more difficult to correct than direct glare. It is caused by the light being reflected from some polished surface or tool, and even white glossy paper will give considerable glare. To minimize this reflected glare it is best to diffuse the light at the sources and shield the direct light from falling on the working place.

A good lighting system is one that is easy to maintain and economical to operate. It should give a steady non-flickering light and give off no impurities into the room. The efficiency of any lighting system is greatly decreased by dust and dirt, so it is important to have units so designed and arranged that they may be easily cleaned.

The electric-filament lamp is standard in most industrial plants today, although the mercury-vapor lamp has some points in its favor. Gas is seldom used.

Mercury-vapor Lighting.

The mercury-vapor lamp consists of a glass tube from 2 to 4 ft. in length and approximately 1 in. in diameter. An enlargement in one end of the tube contains the mercury. An electric current passing through mercury vapor produces a soft, glowing light made up mainly of three colors: yellow, green, and blue. The mercury-vapor lamp produces a very unnatural bluish light which distorts most colors. However, it is claimed for this lamp that it speeds up the seeing process, reduces eye strain and fatigue, and, because of the nature of the light-producing element, diffuses the light very evenly throughout the room. The mercury-vapor lamp has the disadvantage of giving unnatural color, and, in addition, the initial cost as well as the maintenance costs are high.

Distribution of Light.

Distribution of light may be effected in three ways:

1. Direct lighting.
2. Indirect lighting.
3. Semi-indirect lighting.

Direct lighting brings the light to the surface to be illuminated directly from the source. Some protective covering such as a frosted or ribbed shade may be used to diffuse the light effectively. A large frosted or opal shade acts to decrease the brightness of the visible source, and this is desirable.

Indirect lighting brings the light to the surface to be illuminated by redirection or reflection, using, in most cases, the ceilings and walls for this purpose. The source of light is hidden from view by

FIG. 72.—General lighting, showing the use of R. L. M. standard dome reflectors.

some opaque shield or reflecting device. No light is distributed directly from the source.

Semi-indirect lighting combines the methods of both direct and indirect lighting, in that a translucent bowl or shade is used to reflect the light to the ceiling and upper walls and then on down to the surface to be illuminated, as in the case of indirect lighting. But at the same time some light falls directly from the translucent shade and so there are two lighting effects present. In general, it can be said that the indirect lighting is the most expensive and the direct the most economical as to the cost per foot-candle of light at the working surface to be illuminated.

For lighting the factory it is present practice to use the direct method of illumination, since it is the simplest, most effective, easiest to maintain, and certainly the most economical

Methods of Arranging Light Sources.

After the method of the distribution of the light has been determined, there are three methods of arranging the light sources that might be used:

1. General lighting.
2. Group lighting.
3. Local lighting.

General lighting is obtained by an even distribution of overhead sources near the ceiling of the area to be illuminated. The lighting units should have approximately the same intensities and should give a uniform light to all points in the room. This leaves no dark or gloomy areas.

Group lighting is nothing more than localized overhead lighting, modified to give special illumination to groups of machines, benches, or work places. A general lighting layout can be made without reference to the machine layout, while the group cannot.

Local lighting is used where high intensities are required at some point on a machine or over a small area on a desk or work bench. On a lathe or machine of similar nature it is often necessary to have light directed from a horizontal plane, and so a single lamp may be used. Even when local lighting is desirable or necessary it should also be supplemented by general lighting.

Proper Intensity of Light.

For proper industrial lighting there are four general levels of illumination which the designer of a lighting system will do well to keep in mind.[1]

"*Five Ft.-candles.*—Satisfactory for work of a coarse nature, such as rough assembling, rough packing, coal and ash handling, and the like, where the eyes are not called upon to see small details quickly and accurately. This value also would represent an abundance of light for warehouses, stockrooms, and aisles and passageways which were always kept free from obstructions. Enough light to dispel any sense of gloom.

"*Ten to Fifteen Ft.-candles.*—Considered good lighting for most kinds of work on light-colored surfaces and for fairly close work

[1] Factory Lighting Design, *Bull.* 42-B, p. 7, Engineering Dept. National Lamp Works, General Electric Co.

on dark surfaces. Not enough light for examining fine details on dark, light-absorbing surfaces.

"*Fifteen to Twenty-five Ft.-candles.*—Really excellent lighting. In addition to permitting quick and accurate execution of all work except the most exacting, lighting of this kind stimulates the workman and makes for fast and accurate production.

"*Fifty to One Hundred Ft.-candles.*—The upper range of artificial lighting values as judged by present experience. Necessary only in extremely fine, accurate operations and in inspections of very fine details. Usually employed locally and supplemented by general lighting of lower value."

Lighting Terms Defined.

"A foot-candle is a measure of the degree to which a surface is illuminated. It is the unit of intensity and is the direct illumination given by a standard candle when placed in a direct line 1 ft. from the object. If a standard candle were placed inside a hollow sphere of 1 ft. radius, the inner surface of the sphere would be illuminated with an intensity of 1 ft.-candle. The area illuminated would be the area of the sphere of 1 ft. radius or $4\pi = 12.57$ sq. ft. The intensity of illumination on a surface varies inversely as the square of the distance from the source to the surface, if the source dimensions are small in comparison with those of the surface.

A lumen is the unit of light flux and is a measure of the quantity of light emitted by a source. In the above example of a standard candle placed in the center of a hollow sphere whose radius is 1 ft., if an opening of 1 sq. ft. area were made in the surface of the sphere, the quantity of light escaping would be 1 lumen. The total quantity over the inner surface of the sphere would be 4π, or 12.57 lumens. The number of lumens required on any surface is the product of the area in square feet and the intensity of illumination desired in foot-candles. For example, if an average intensity of 6 ft.-candles is desired over a surface of 1,000 sq. ft., then 6,000 lumens must be delivered to the surface.

The coefficient of utilization indicates the effectiveness with which the generated lumens reach the surface to be illuminated. Not all of the light emitted reaches the plane of work;[1] some is

[1] Plane of work is an imaginary plane at a distance above the floor at which a person commonly works at a machine, bench, or desk. Two and one-half feet is often used for this distance.

absorbed in the reflector, some in the walls and ceilings, and this coefficient is affected by the size, shape, and proportions of the room, the nature of the wall surfaces, and the color of the interior as well as the relative locations of the light sources. The fact that the color of the walls and ceiling affects the amount of light reflected is shown by the data in Table X. Table XIII gives the coefficients of utilization for the various conditions indicated.

TABLE X.—REFLECTION OF COLORED SURFACES

Color	Reflection, per cent	Absorption, per cent
White	81	19
Pearl gray	70	30
Buff	59	41
Medium gray	35	65
Cocoanut brown	22	78
Olive green	14	86

A depreciation factor is used to give an increased illumination to an installation to provide for losses due to aging of the lamps and for decreased efficiency of the reflectors and bulbs, and also due to the accumulation of dust and dirt.

Steps in Designing a General Lighting System.

1. *Selection of the Intensity of Illumination.*—Sufficient light must be provided in order to prevent spoilage and accidents, to prevent eye strain and fatigue to the worker, to give a cheerful atmosphere to the shop, and in general to aid in increasing production. It is estimated that the difference between good and poor illumination can very easily cause a difference of from 8 to 25 per cent in the output of the worker.

2. *Selection of Lighting Units.*—An exposed electric-light bulb without reflector or shade should never be used. A good reflector should direct the light downward on to the working plane and also protect the eye from the bare light filament. As a further aid a frosted shade or bowl may be placed over the bulb which will diffuse the light and decrease the brightness of the source, thus protecting the eye from the direct glare. For general factory lighting the dome reflector with a bowl-frosted lamp is in general use today. This combination gives most of the desirable qualities

of a good lighting unit and it is very efficient, durable, and easily cleaned. The reflector is made of pressed steel with blue-white enamel baked on the inside and dark green on the outside. The slightly curved surface in the reflector diffuses and reflects the light and the wide rim shields the eye from the filament. If the bowl-frosted bulb is used, the eye is further protected.

3. *Determination of the Coefficient of Utilization.*—From Table XIII the coefficient is indicated and can be found after the room index is determined. The walls and ceilings are usually painted white but most of the wall space will be composed of windows which have a reflection factor equivalent to that of dark walls.

4. *Depreciation Factor.*—This factor varies with the nature of the work done in the plant. Where dusty and dirty operations

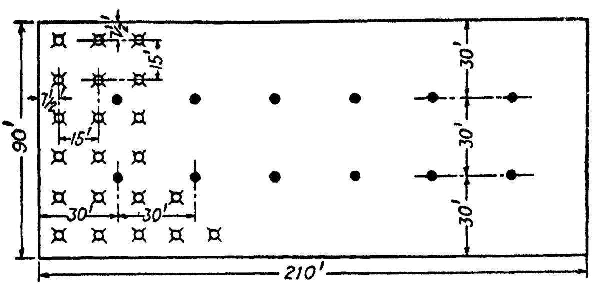


FIG. 73.—Floor plan of the Carver Washing Machine Company, Machine Shop No. 4, showing lighting outlets.

take place and where the lighting units are not kept clean, a low factor must be used. The factors commonly used run from 0.70 to 0.85.

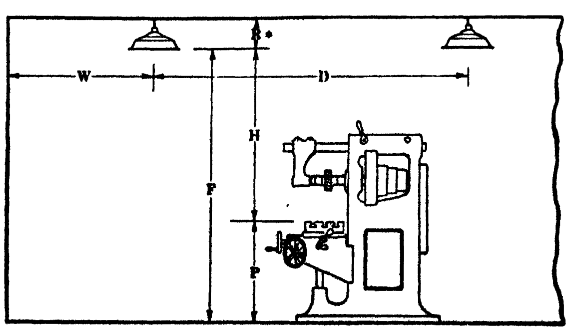
5. *Determination of the Number and Location of the Outlets and the Mounting Heights.*—Table XI gives the spacing and mounting heights for direct lighting units. It is usually best to find a symmetrical layout of lighting units and it is well to study the possible location of the units with respect to the position of the columns of the building and then space an equal number of outlets to each bay. When one outlet will not provide sufficient illumination and where four outlets are too many, it may be best to place the two outlets on diagonals in each bay. Figure 73 shows a floor plan and lighting layout of the Carver Washing Machine Company. The positions of the columns as well as the outlets are indicated.

TABLE XI.—TABLE FOR DETERMINING PROPER SPACING BETWEEN OUTLETS AND PROPER MOUNTING HEIGHT ABOVE WORK OR FLOOR

Mounting height of unit		Permissible distance between outlets	Permissible distance between outlets and sidewalls	
Above plane of work (*H*)	Above floor[1] (*F*)	(*D*)	In usual locations where aisles and storage are next to wall (*W*)	In offices or where work benches are next to wall (*W*)
4	6½	6	3	2
5	7½	7½	3½	2½
6	8½	9	4½	3
7	9½	10½	5	3½
8	10½	12	6	4
9	11½	13½	6½	4½
10	12½	15	7½	5
11	13½	16½	8	5½
12	14½	18	9	6
13	15½	19½	9½	6½
14	16½	21	10½	7
15	17½	22½	11	7½
16	18½	24	12	8
18	20½	27	13½	9
20	22½	30	15	10
22	24½	33	16½	11
24	26½	36	18	12
27	29½	40½	20	13½
30	32½	45	22½	15
35	37½	52½	26	17½
40	42½	60	30	20

Courtesy of the National Lamp Works.

[1] Plane of work (*P*) assumed to be 2½ ft. above floor. When the plane of work is higher or lower than 2½ ft. above floor, neglect column (*F*) and work from column (*H*).



* Minimum allowance for (*R*) usually 1 ft.

TABLE XII.—ROOM INDEX FOR LARGE, HIGH ROOMS

		Feet							
For indirect lighting use ceiling height..		14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	37 to 50		
For direct lighting use mounting height		10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	37 to 50
Room width, feet	Room length, feet	Room index							
14 (13 to 15½)	14 to 20	1.0	0.8	0.6	0.6				
	20 to 30	1.0	0.8	0.6	0.6				
	30 to 42	1.2	1.0	0.8	0.6	0.6			
	42 to 60	1.5	1.0	0.8	0.6	0.6	0.6		
	60 to 90	1.5	1.2	1.0	0.6	0.6	0.6		
	90 up	1.5	1.5	1.2	0.8	0.6	0.6		
17 (16 to 18½)	14 to 20	1.0	0.8	0.6	0.6				
	20 to 30	1.2	1.0	0.8	0.6				
	30 to 42	1.2	1.0	1.0	0.6	0.6	0.6		
	42 to 60	1.5	1.2	1.2	0.8	0.6	0.6	0.6	
	60 to 110	1.5	1.2	1.2	0.8	0.6	0.6	0.6	
	110 up	2.0	1.5	1.2	1.0	0.8	0.6	0.6	
20 (19 to 21½)	20 to 30	1.2	1.0	0.8	0.6	0.6			
	30 to 42	1.5	1.2	1.0	0.8	0.6	0.6		
	42 to 60	2.0	1.5	1.2	0.8	0.6	0.6	0.6	
	60 to 90	2.0	1.5	1.2	1.0	0.6	0.6	0.6	
	90 to 140	2.0	1.5	1.5	1.0	0.8	0.8	0.6	0.6
	140 up	2.0	1.5	1.5	1.0	1.0	0.8	0.6	0.6
24 (22 to 26)	20 to 30	1.5	1.2	1.0	0.8	0.6	0.6		
	30 to 42	1.5	1.2	1.2	0.8	0.6	0.6		
	42 to 60	2.0	1.5	1.2	1.0	0.8	0.6	0.6	
	60 to 90	2.0	1.5	1.5	1.0	0.8	0.6	0.6	0.6
	90 to 140	2.0	2.0	1.5	1.2	1.0	0.8	0.6	0.6
	140 up	2.0	2.0	1.5	1.2	1.0	0.8	0.8	0.6
30 (27 to 33)	30 to 42	2.0	1.5	1.2	1.0	0.8	0.6	0.6	
	42 to 60	2.5	1.5	1.5	1.0	1.0	0.8	0.6	
	60 to 90	2.5	2.0	1.5	1.2	1.0	0.8	0.6	0.6
	90 to 140	2.5	2.0	2.0	1.5	1.2	1.0	0.8	0.6
	140 to 180	2.5	2.0	2.0	1.5	1.2	1.0	0.8	0.6
	180 up	2.5	2.0	2.0	1.5	1.2	1.0	0.8	0.6
36 (34 to 39)	30 to 42	2.0	1.5	1.5	1.0	0.8	0.8	0.6	
	42 to 60	2.5	2.0	1.5	1.2	1.0	0.8	0.6	0.6
	60 to 90	3.0	2.0	2.0	1.5	1.0	1.0	0.6	0.6
	90 to 140	3.0	2.5	2.0	1.5	1.2	1.0	0.8	0.6
	140 to 200	3.0	2.5	2.0	1.5	1.5	1.2	1.0	0.8
	200 up	3.0	2.5	2.0	1.5	1.5	1.2	1.0	0.8
42 (40 to 45)	42 to 60	3.0	2.0	1.5	1.2	1.0	0.8	0.8	0.6
	60 to 90	3.0	2.5	2.0	1.5	1.2	1.0	0.8	0.6
	90 to 140	3.0	2.5	2.5	2.0	1.5	1.2	1.0	0.6
	140 to 200	3.0	2.5	2.5	2.0	1.5	1.2	1.0	0.8
	200 up	3.0	2.5	2.5	2.0	1.5	1.5	1.2	0.8
50 (46 to 55)	42 to 60	3.0	2.5	2.0	1.5	1.2	1.0	0.8	0.6
	60 to 90	3.0	3.0	2.5	1.5	1.5	1.2	1.0	0.6
	90 to 140	3.0	3.0	2.5	2.0	1.5	1.5	1.2	0.8
	140 to 200	3.0	3.0	2.5	2.0	2.0	1.5	1.2	0.8
	200 up	3.0	3.0	2.5	2.0	2.0	1.5	1.2	1.0
60 (56 to 67)	60 to 90	4.0	3.0	2.5	2.0	1.5	1.2	1.0	0.8
	90 to 140	4.0	3.0	3.0	2.5	2.0	1.5	1.2	1.0
	140 to 200	4.0	3.0	3.0	2.5	2.0	1.5	1.5	1.0
	200 up	4.0	3.0	3.0	2.5	2.0	2.0	1.5	1.0
75 (68 to 90)	60 to 90	5.0	4.0	3.0	2.5	2.0	1.5	1.2	0.8
	90 to 140	5.0	4.0	3.0	2.5	2.0	1.5	1.5	1.0
	140 to 200	5.0	4.0	4.0	3.0	2.5	2.0	1.5	1.2
	200 up	5.0	4.0	4.0	3.0	2.5	2.0	1.5	1.2
90 or more	60 to 90	5.0	4.0	3.0	2.5	2.0	1.5	1.2	1.0
	90 to 140	5.0	5.0	4.0	3.0	2.5	2.0	1.5	1.2
	140 to 200	5.0	5.0	4.0	3.0	2.5	2.0	1.5	1.2
	200 up	5.0	5.0	4.0	3.0	3.0	2.5	2.0	1.5

Courtesy of the Edison Lamp Works.

6. *Determination of Lamp Sizes.*—There are several methods of determining the size of the lamps to be used. A very common and simple method is given here:

$$\text{Area in square feet per outlet} = \frac{\text{total floor area in square feet}}{\text{number of outlets in room}}.$$

$$\text{Lamp lumens required per square foot} = \frac{\text{foot-candles}}{\text{depreciation factor} \times \text{coefficient of utilization}}.$$

$$\begin{array}{c}\text{Lamp lumens}\\ \text{required per}\\ \text{outlet}\end{array} = \begin{array}{c}\text{Area in}\\ \text{square feet}\\ \text{per outlet}\end{array} \times \begin{array}{c}\text{Lamp lumens}\\ \text{required per square}\\ \text{foot.}\end{array}$$

After the lumens output per square foot is determined, then it is necessary to find a unit that will supply this amount. Table XIV gives data for Mazda lamps and from this table a suitable lamp can be found.

A General Lighting Installation for a Factory. Sample Problem.

The following requirements must be met in the lighting installation for the Carver Washing Machine Co., shop 4.

1. General lighting for the machine shop doing light-manufacturing work.
2. Intensity of illumination desired: 10 ft.-candles average.
3. Three-story reinforced concrete building, flat-slab construction: length, 210 ft.; width, 90 ft. (30-ft. bays).
4. Height of ceiling above floor, 14 ft.
5. Interior of building painted white, glass side walls.
6. Mazda C, clear-filament electric lamps to be used, 110 to 125 volts.
7. Reflector: R.L.M. (Reflector and lamp manufacturers') standard dome
8. Working plane 2½ ft. above floor with 1½ ft. allowed for the reflector drop.
9. Depreciation factor to be allowed: 0.75.

Solution.—From Table XI the spacing-mounting height can be found. The dimension H equals the ceiling height minus the allowance for reflector drop and also the height of the working plane above the floor. Or

$$H = 14 \text{ ft.} - (2\tfrac{1}{2} \text{ ft.} + 1\tfrac{1}{2} \text{ ft.}) = 14 \text{ ft.} - 4 \text{ ft.} = 10 \text{ ft.}$$

Where H equals 10 ft. (Table XI), the permissible distance between outlets is 15 ft. with 7.5 ft. from walls when no machines or benches are located next to the walls. With this information it now becomes possible to make the layout of the outlets as shown in Fig. 73.

$$\text{Area in square feet per outlet} = \frac{\text{total floor area in square feet}}{\text{number of outlets}} \qquad (1)$$

$$= \frac{90 \times 210}{14 \times 6} = \frac{18{,}900}{84} = 225 \text{ sq. ft.}$$

$$\left.\begin{array}{c}\text{Lamp lumens required}\\ \text{per square foot}\end{array}\right\} = \frac{\text{foot-candles}}{\text{depreciation factor} \times \text{coefficient of utilization}} \qquad (2)$$

The coefficient of utilization is found from Table XIII. Table XII gives the room index as 5 for direct lighting with mounting height of 12½ ft., room width 90 ft., and room length 200 ft. or more. With the room ratio as 5 and with the light-colored ceilings and dark walls (glass walls, or windows, have a reflection value equivalent to that of dark walls) the coefficient of

TABLE XIII.—COEFFICIENTS OF UTILIZATION

Probable average illumination, per cent of initial illumination			Ceiling	Very light (70 %)			Fairly light (50 %)			Fairly dark (30 %)	
			Walls	Fairly light (50 %)	Fairly dark (30 %)	Very dark (10 %)	Fairly light (50 %)	Fairly dark (30 %)	Very dark (10 %)	Fairly dark (30 %)	Very dark (10 %)
Clean conditions	Average conditions	Dirty conditions	Room index	Coefficients of utilization							
Calculation Data: Direct-lighting Porcelain-enamel Reflectors R.L.M. dome, clear lamp											
0.85	0.80	0.70	0.6	0.34	0.29	0.24	0.34	0.29	0.24	0.28	0.24
			0.8	0.42	0.38	0.34	0.42	0.37	0.33	0.37	0.33
			1.0	0.46	0.43	0.39	0.45	0.42	0.39	0.42	0.39
			1.2	0.50	0.47	0.43	0.49	0.46	0.43	0.45	0.42
			1.5	0.53	0.50	0.46	0.52	0.49	0.46	0.48	0.45
			2.0	0.58	0.55	0.51	0.57	0.54	0.51	0.53	0.51
			2.5	0.62	0.59	0.56	0.61	0.58	0.56	0.58	0.56
			3.0	0.64	0.61	0.58	0.63	0.60	0.58	0.60	0.58
			4.0	0.67	0.65	0.63	0.66	0.64	0.62	0.63	0.61
			5.0	0.69	0.67	0.65	0.67	0.66	0.64	0.65	0.63
R.L.M. dome, white bowl or inside-frosted lamp											
0.85	0.80	0.70	0.6	0.32	0.28	0.25	0.32	0.28	0.25	0.27	0.25
			0.8	0.40	0.36	0.34	0.39	0.35	0.33	0.35	0.33
			1.0	0.43	0.39	0.37	0.42	0.39	0.37	0.39	0.37
			1.2	0.46	0.43	0.41	0.45	0.43	0.41	0.43	0.41
			1.5	0.48	0.45	0.43	0.47	0.45	0.43	0.45	0.43
			2.0	0.52	0.50	0.48	0.51	0.49	0.47	0.49	0.47
			2.5	0.56	0.54	0.52	0.55	0.53	0.51	0.53	0.51
			3.0	0.57	0.55	0.53	0.56	0.54	0.52	0.54	0.52
			4.0	0.60	0.58	0.56	0.59	0.57	0.55	0.57	0.55
			5.0	0.61	0.59	0.57	0.60	0.58	0.57	0.58	0.56
Glassteel diffuser, clear lamp											
0.80	0.75	0.65	0.6	0.29	0.25	0.21	0.28	0.24	0.21	0.23	0.21
			0.8	0.36	0.32	0.29	0.35	0.31	0.28	0.31	0.28
			1.0	0.39	0.36	0.33	0.38	0.35	0.33	0.34	0.32
			1.2	0.42	0.39	0.36	0.41	0.38	0.36	0.37	0.35
			1.5	0.45	0.42	0.39	0.43	0.40	0.38	0.39	0.38
			2.0	0.49	0.46	0.43	0.48	0.45	0.43	0.44	0.42
			2.5	0.53	0.50	0.47	0.51	0.49	0.47	0.47	0.46
			3.0	0.54	0.52	0.49	0.52	0.50	0.49	0.49	0.47
			4.0	0.57	0.55	0.53	0.55	0.53	0.51	0.51	0.50
			5.0	0.58	0.56	0.54	0.56	0.54	0.53	0.52	0.51

Courtesy of the Edison Lamp Works.

TABLE XIV.—LAMP DATA

Mazda C lamps

	110, 115, and 120 volts								
Watts	50*	60*	100*	150	200	300	500	750	1,000
Lumens, per watt	10.8	11.1	13.2	15.2	16.1	17.4	18.8	19.7	21.0
Total lumens	540	660	1,320	2,280	3,220	5,220	9,400	14,770	21,000

Mazda daylight lamps

Watts	60*	100*	150	200	300	500			
Total lumens (approx.)	430	870	1,500	2,100	3,400	6,400			

* Inside frosted.

utilization is 0.65 from the Table XIII, for R.L.M. dome reflector, clear lamp.

Now, substituting in Eq. (2):

$$\text{Lamp lumens required per square foot} = \frac{10}{0.75 \times 0.65} = 20.5.$$

$$\begin{array}{c} \text{Lamp lumens} \\ \text{required per} \\ \text{outlet} \end{array} = \begin{array}{c} \text{Area in square feet} \\ \text{per outlet} \\ \text{(from (1))} \end{array} \times \begin{array}{c} \text{Lamp lumens required} \\ \text{per square foot} \\ \text{(from (2))} \end{array} \qquad (3)$$

$$= 225 \times 20.5 = 4{,}613 \text{ lumens.}$$

Referring to Table XIV, it is apparent that a 300-watt standard Mazda C lamp on 110- to 125-volt circuit will give 5,220 lumens, which is satisfactory.

PART II

TIME AND MOTION STUDY, WAGES, AND MANUFACTURING COSTS

CHAPTER VII

TIME AND MOTION STUDY. STOP-WATCH TIME STUDY

Time study has two main purposes: First, it is used to determine the best method of doing work. This involves motion study of the operations as well as the standardization of all of the conditions surrounding the job. Second, time study may be used for setting rates, that is, as the basis for some wage-incentive system. The standard time which is determined by time study can be used with almost any of the different premium, bonus, or piece-rate plans for paying the workers. Besides these two purposes, time-study standards are used for cost calculations and reports, for estimating delivery dates of orders, for aiding in the planning and scheduling of work through the factory, and for other phases of production control.

Standardization.

Time study can be of little value as a basis for rate setting unless conditions are standardized for the job. That means that the method of doing the work, the tools to be used, the fixtures and jigs or clamps must be specified for the work. The speeds and feeds of the machine must be correct, the material must be standardized as to size, shape, and quality. The conditions in the shop and those surrounding the worker must be maintained identical with those which were present when the time study was made. This, of course, assumes that the best conditions and methods possible are determined and set up before the actual study is made. Motion study aids in the determination of the most effective motions and shows the unnecessary ones which the operator should be trained to omit. Motion study further aids in selecting the proper sequence of useful motions. In one plant, for example, the correct method of performing an assembly operation was determined after a very detailed study of the motions made by the hands and feet of the operator. Now, this "best method" is taught to every person who does this kind

of work. A school is maintained and a training period of about 6 weeks is required before the average operator develops sufficient skill to perform this one operation which is but a fraction of a minute in length. Since there are over 150 employees working on this one operation, it was found profitable to make such a detailed study of the job.

Equipment Used for Time Study.

The most common method of time study requires a decimal stop watch. The minute-decimal watch (Fig. 74) has the dial divided into 100 equal spaces, each of which represents 0.01 min., the hand making one complete revolution each minute. A smaller dial on the watch is divided into 30 spaces, each representing 1 min. of time. The hour-decimal watch has the dial divided into 100 spaces, each of which represents 0.0001 hr., the hand making 100 revolutions per hour. The small dial on this watch is divided into 30 spaces, each representing 0.01 hr. of time. The hands of this watch may be snapped back to zero by pressing the stem *B* of the watch, or they may be locked in position by moving the slide *A* on the left side of the watch case. A light board slightly larger than the time-study sheet is used to hold the paper and the watch. A speed counter, tachometer, slide rule, and speed rules are usually part of the necessary equipment for time-study work.

Fig. 74.—Minute-decimal stop watch.

Methods of Reading the Stop Watch.

The two principal methods of reading the stop watch are the snap-back or repetitive method and the continuous method. In the snap-back method the watch is started at the beginning of the first element by pressing the stem of the watch, which snaps the hand back to zero and permits it to move forward instantly. At the end of the first element the watch is read and the hand is again snapped back to zero and instantly moves forward, measuring the time of the second element, etc. This method gives the direct time without subtractions and the data are

recorded on the time-study sheet as read from the watch. Figure 78 shows a time-study sheet suitable for recording snap-back readings.

When time studies are made by the continuous method, the same stop watch may be used as for the snap-back method, but

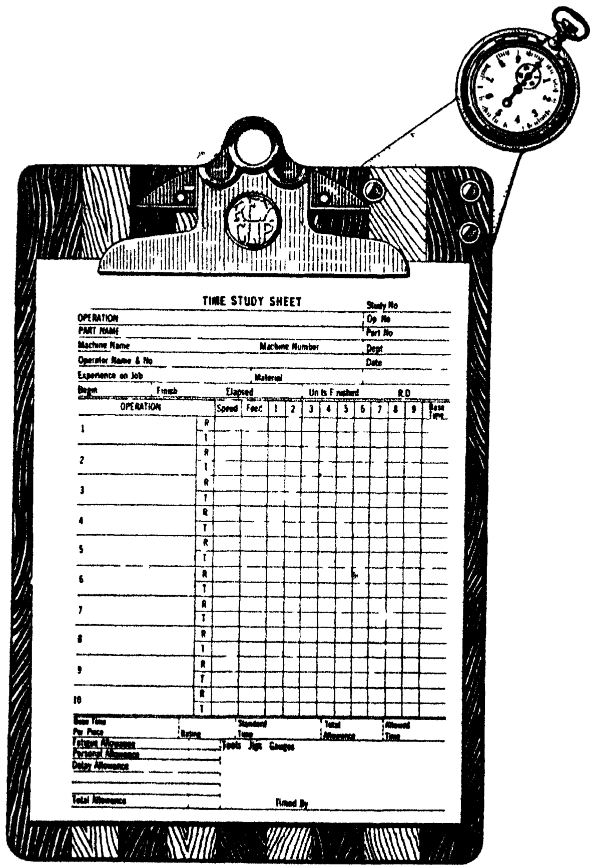


FIG. 75.—Time-study board with time-study sheet for recording data taken by the continuous method

in this case the watch is permitted to run continuously from the beginning of the first element to the end of the operation. At the end of each element the position of the hand is noted and this reading is recorded on the time-study sheet. In order to find the time for each element it is necessary to subtract each reading from the one following. Figure 75 shows a minute-decimal

watch and a time-study sheet suitable for recording continuous readings. In general, it can be said that the continuous method is more satisfactory for time-study work.

It is sometimes desirable to use two stop watches, as shown in Fig. 76. Slides *A* of the two watches are linked together by the bar *C* in such a manner that by pressing *C* to the right the lower watch is started and the upper watch is stopped, the hand

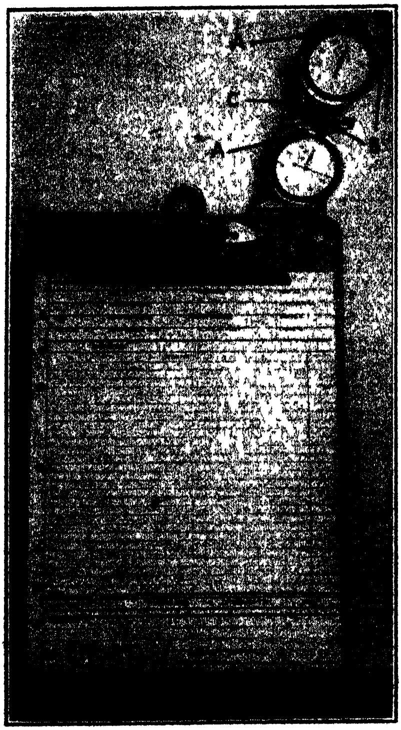


Fig. 76.—Time-study board showing two minute-decimal stop watches.

of the upper watch being stopped in position. Therefore, this watch can be read and the hand then snapped back to zero by pressing the stem *B* of the watch. The watch is then in readiness for the timing of the next element. When bar *C* is moved to the left, the upper watch is started and the lower one is stopped, and it is then read and snapped back to zero, as was the upper watch before. The use of two watches tends to eliminate errors in reading the watch, since the reading does not need to be made while the hands of the watch are in motion.

Methods for Determining Time Standards.

There are three ways of arriving at a standard or "task" time. First, a time study may be made in the shop while the operation is being performed. This method is the most common and the stop watch is usually used for taking the time elements of the operation, although a motion-picture camera is sometimes used.

Second, time standards may be set from standard data, these data having been accumulated and tabulated for fundamental elements and being the result of many time studies. Where several elements occur over and over again it is possible to set a standard time for each of these fundamental elements and then they need not be timed when further studies of similar work are made. A fundamental element might be defined as a single direct complete motion of the operator or the machine, which cannot be further divided into shorter motions. For example, in Fig. 78, a time study is shown for drilling a ¼-in. hole on a single-spindle Avey drill, hand feed. Element three of the study, "lower drill to piece," would be a single, direct, complete motion of the operator's right arm and could be considered as a fundamental element for many drilling operations.

Third, formulas can often be developed which make it possible to determine time standards entirely from accumulated data. It is desirable to have the data in the form of charts

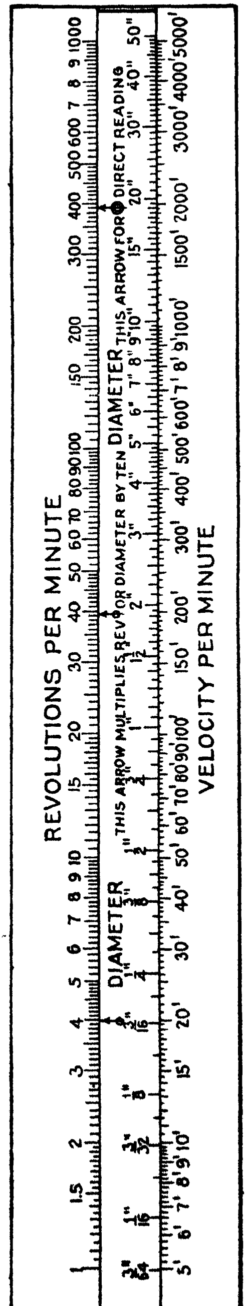


Fig. 77.—Speed slide rule. With the aid of this rule it is possible to convert r.p.m. into surface velocity (in feet per minute) or *vice versa*, with one setting of the slide.

and tables in order to facilitate the use of the formulas and simplify the calculations required.

The Stop-watch Time Study.

Figure 78 shows a time-study sheet used by a machine-tool plant and it is much like that used by many other industries.

TIME STUDY SHEET

PART NAME: *Adjusting Screw*	CUSTOMER: *Wiss Machine Co.*	PART No.: *S 135*
OPERATION NAME: *Drill 1/4" Hole*		OPERATION No: *Dr. 20*
DEPT: *12-D* MAN'S NAME & No: *J S. Smith 1562*	BRINELL READING	MATERIAL: *S.A E 2315*
MACH. No.: *D49C60* MACH NAME & CLASS: *Avey Single Spindle #60*	No. PCS. ON ORDER: *250*	ORDER No.: *A.S 1463R*

OPERATION

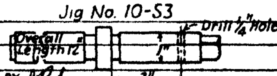
	SPEED	FEED	1	2	3	4	5	6	7	8	9	BASE	TIME
1 Pick Up Piece and Place in Jig			11	.12	.09	.13	.11	.12	11	.10	.12		
2 Tighten Thumb Screw			.09	07	08	.08	.09	.10	.08	.07	.06		
3 Lower Drill to Piece			04	.03	.03	.04	.05	.04	.04	.03	04		
4 DRILL 1/4" HOLE	980	H	45	.48	44	.46	47	.46	.46	45	.43		
5 Raise Drill			04	.03	04	.04	.03	.03	.03	.02	.04		
6 Loosen Thumb Screw			.04	.05	.06	.06	.05	.05	.04	.05	04		
7 Remove Piece from Jig			.07	08	.10	.08	.08	.06	.08	.07	09		
8 Blow Out Jig			.13	14	10	.11	.13	.12	.12	17	.14		
9 (Overall Time)			.98		.96		105		.96		.98		
10													
11 (1)			11	.12	12	.13	.11	.12	.09	.14	.12		.12
12 (2)			.07	.08	.07	.09	.08	.09	.08	.10	.08		08
13 (3)			04	.03	.05	04	.04	.03	.04	12	.03		04
14 (4)			.45	.47	.51	.46	.44	.47	.46	.49	.46		.46
15 (5)			.02	03	.03	04	.03	03	.04	.03	05		.03
16 (6)			.05	.06	.05	.09	05	.21	05	04	.07		.05
17 (7)			07	.08	.09	.08	.06	.08	.08	.10	.11		.08
18 (8)			12	.12	13	.11	.09	.09	.12	.13	.12		.12
19 (Overall Time)			93		1.06		.91		.95		106		

20 Element	1	2	3	4	5	6	7	8
21	.09-//	.06-/	.03-///// /	.43-/	02-//	.04-////	.06-//	09 //
22	.10-/	.07 ////	.04 ///// /////✓	44-//	03-/////-////✓	.05-///// ////✓	07-///	.10-/
23	11-/////	.08-///// //✓	.05-//	45-///	04-///// /	06 ///	08-///// ////✓	11-//
24	.12-/////-//✓	.09-////		.46-///// ////✓	.05-/	.07-/	.09-//	12-///// /✓
25	.13-//	.10-//		47-///		.08-	10-//	.13-////
26	.14-/			.48-/		.09-/	.11-/	.14-//
TOTAL			.49	.51-///				.17-/

BASE TIME PER PIECE *.98* ALLOWANCE *10 %* STANDARD TIME *1.1* MIN.

REMARKS *Use H.S. Drills 1/4" Diam* *Jig No. 10-S3*

BEGIN - 9:12, END - 9:33, FIN 18 PCS. — *Hand Feed-Use Oil*; *Speed Setting "FAST"*



DATE *1-12-26* TIMED BY *J.R.S.*

FIG. 78.—Time study made by the snap-back method.

It will be assumed that the conditions and methods for drilling the ¼-in. hole in the adjusting screw have all been studied and are the best that can be used under present circumstances. A jig is available for drilling the hole because it is important that the hole be located exactly 3 in. from the shoulder and that it be in the center of the shaft. The speed and feed chart shown

in Fig. 79 is consulted in order to determine whether the drill is running at the correct speed for a 1/4-in. high-speed drill, hand feed.

Diameter of drills, inches	100 ft. per min.		90 ft. per min.		70 ft. per min.		40 ft. per min.	
	Bronze and brass		Cast iron		Medium steel		Tool steel	
	R.p.m.	Feed, inches	R.p.m.	Feed, inches	R.p.m.	Feed, inches	R.p.m.	Feed, inches
1/8	3,100	0.010	2,810	0.004	2,130	0.004	1,220	0.006
3/16	2,050	0.010	1,840	0.006	1,420	0.006	810	0.006
1/4	1,550	0.010	1,390	0.010	1,070	0.007	605	0.006
5/16	1,220	0.012	1,100	0.010	850	0.010	485	0.007
3/8	1,020	0.012	915	0.010	710	0.010	405	0.007
7/16	870	0.015	780	0.013	608	0.010	347	0.009
1/2	760	0.015	685	0.013	530	0.010	303	0.009
9/16	680	0.020	610	0.015	472	0.012	270	0.010
5/8	610	0.030	545	0.015	425	0.014	242	0.012
11/16	560	0.030	500	0.015	388	0.014	220	0.012
3/4	500	0.030	455	0.015	355	0.014	203	0.012
13/16	470	0.030	420	0.015	327	0.014	187	0.012
7/8	435	0.030	390	0.018	305	0.014	173	0.012
15/16	405	0.030	355	0.018	283	0.014	162	0.012
1	380	0.030	340	0.018	267	0.014	152	0.012
1 1/8	340	0 030	300	0.018	237	0.014	135	0.012
1 1/4	300	0.030	275	0.018	212	0.014	122	0.012
1 3/8	275	0.030	245	0.018	193	0.014	110	0.012
1 1/2	250	0.030	225	0.018	178	0.014	102	0.012
1 5/8	230	0.025	210	0.014	163	0.010	94	0.007
1 3/4	215	0.025	195	0.014	152	0.010	87	0.007
1 7/8	200	0.020	180	0.014	142	0.010	82	0.007
2	190	0.020	170	0.014	133	0.010	76	0.007
2 1/8	175	0.020	160	0.014	125	0.010	72	0.007
2 1/4	165	0.020	150	0.014	118	0.010	67	0.007
2 3/8	160	0.020	145	0.014	112	0.010	64	0.007
2 1/2	150	0.020	135	0.014	107	0.010	61	0.007
2 5/8	145	0.020	130	0.014	102	0.010	57	0.007
2 3/4	135	0.020	123	0.014	97	0.010	55	0.007
2 7/8	130	0.020	117	0.014	92	0.010	53	0.007
3	125	0.020	113	0.014	87	0.010	50	0.007

Fig. 79.—Speed and feed chart for drilling.

The time-study observer fills in the heading of the time-study sheet with the information from the drawing of the piece and

from the operation sheet which accompanies it. Any other necessary data are listed at the bottom or on the back of the sheet. The operation is then divided into its elements and these are listed. It seems desirable to divide this operation into eight elements. The first three and the last four are called "handling time" and the fourth, "drill hole, "machine time." In every time study, machine time is kept separate from handling time. This is desirable because one is a function of the operator and the other of the tools. After the elements are listed on the sheet the the watch is used and the time for each element is recorded. The snap-back method is used on this study. A second stop watch is often used for taking the overall time of the operation. Also, a clock time may be made of the entire time required for the operator to drill the 18 pieces studied. This information is recorded on the time-study sheet. The number of pieces that should be timed is determined by the judgment of the observer. Eighteen sets of readings were made in this study.

Determination of the Base Time and the Time Standard.

After all the data are recorded, a drawing or sketch of the part is made on the bottom or back of the time-study sheet and the data are then ready to be analyzed in order to determine the elements that are representative of the time required to perform the operation. The data are first examined for the purpose of discarding any high or low readings. If a reading is considerably higher or lower than the preceding or following ones, it is an indication that there has been an error in reading the watch or in recording the data, and such readings should not be considered in the determination of the base time.

The four methods for finding the "selected time" or "base time" for an operation are: (1) minimum, (2) average, (3) modal, and (4) "good time." There is little to be said in favor of the method of selecting the minimum time as the base. The second method is much more commonly used—that of taking the average of the readings. By the modal method is meant the selection of the time element that occurs most frequently. This method is perhaps the most satisfactory of any and it is widely used. The good-time method permits the time-study observer to use his judgment in modifying the mode. A time which occurs frequently may be selected rather than the one that occurs most frequently.

The modal method was used in determining the base time for the time study shown in Fig. 78. For the first element, "pick up piece and place in jig," 0.12 min. occurred seven times, while 0.11 occurred five times and 0.13 twice. Therefore, 0.12 is used for the selected operation time for this element. In a like manner, the other time elements are selected and the total of these is called the selected operation time or the base time. This base time is 0.98 min. for this operation. A total allowance of 10 per cent is added to the base time giving a standard time of 1.1 min. for the operation.

TABLE XV.—TIME-SETTING TABLE FOR SENSITIVE DRILLS

Chucking and removing time

1. Work held in jig.

   Classes:

   A. Held by thumb screw.
   B. Held by set screw.
   C. Held by thumb and set screw.
   D. Held by cover strap and thumb screw.
   E. Held by cover strap and set screw.
   F. Held by cover strap, thumb screw, and set screw.

Operations	Time, hundredths of a minute					
	A	*B*	*C*	*D*	*E*	*F*
1. Pick up piece and place in jig	12	12	12	12	12	12
2. Swing cover strap and tighten lock screw	..	..	..	10	10	10
3. Tighten thumb screw	08	..	08	08	..	08
4. Tighten set screw	..	12	12	..	12	12
5. Loosen set screw	..	06	06	..	06	06
6. Loosen thumb screw	05	..	05	05	..	05
7. Swing cover strap back and loosen lock screw	..	..	..	08	08	08
8. Remove piece from jig	08	08	08	08	08	08
9. Blow out jig	12	12	12	12	12	12
Total	45	50	63	63	68	81

NOTE.—Add 0.32 when jig is strapped to table.
Add 0.07 for each additional thumb screw.
Add 0.08 for each additional set screw.

TABLE XVI.—TIME-SETTING TABLE FOR SENSITIVE DRILLS

Chucking and removing time

2. Work held by strap.

Classes:

A. Held by one strap.
B. Held by two straps.
C. Held by three straps.
D. Held by drawbolt and washer
E. Held by table stops.

Operations	Time, hundredths of a minute				
	A	*B*	*C*	*D*	*E*
1. Pick up piece and place on table	06	06	06	06	06
2. Place strap and tighten	20	40	60		
3. Place drawbolt washer and tighten	..	..	..	20	
4. Loosen drawbolt washer and remove	..	..	..	12	
5. Loosen strap and remove	12	24	36		
6. Remove piece from table	05	05	05	05	05
7. Blow off table	06	06	06	06	06
Totals	49	81	113	49	17

TABLE XVII.—TIME-SETTING TABLE FOR SENSITIVE DRILLS

Chucking and removing time

3. Work held in vise.

Classes:

A. Small work.
B. Work lined up.
C. Vise tightened with lead hammer.
D. Work lined up and vise tightened with lead hammer.

Operations	Time, hundredths of a minute			
	A	*B*	*C*	*D*
1. Pick up piece and place in vise	08	08	08	08
2. Line up work	..	10	..	10
3. Tighten vise	05	05		
4. Tighten vise using lead hammer	..	..	10	10
5. Loosen vise and remove piece	08	08		
6. Loosen vise using lead hammer and remove piece	..	..	12	12
7. Blow out vise	04	04	04	04
Totals	25	35	34	44

TABLE XVIII.—TIME-SETTING TABLE FOR SENSITIVE DRILLS

Machine manipulation time

Classes:

A. Drilling, one drill and no bushing.
B. Drilling, placing, and removing bushing.
C. Drilling, placing, and removing drill.
D. Drilling, placing, and removing drill and bushing.

Operations	Time, hundredths of a minute			
	A	*B*	*C*	*D*
1. Place bushing in jig	..	06	..	06
2. Place drill in chuck	..	..	04	04
3. Advance drill to hole	04	04	04	04
4. Raise drill from hole	03	03	03	03
5. Remove bushing from jig	..	05	..	05
6. Remove drill from chuck	..	..	03	03
Totals	07	18	14	25

NOTE.—Add 0.15 when quick-change chuck is not used (cases *B* and *C*).
Add 0.06 for advancing work to next spindle.
Add 0.05 when reamer is oiled before entering hole.

TABLE XIX.—TIME-SETTING TABLE FOR SENSITIVE DRILLS

Set-up time on sensitive drills (Avey, Sipp, Edlund, and Turner)

Description of work	Time, minutes
1. Small work held in jig which can be handled very easily by hand	15.00
2. Small work held in vise	15.00
3. Small work which is held to table by one or two straps	15.00
4. Small work held in jig having a number of drilled, tapped, and reamed holes	30.00
5. Small work held in jig and jig held in vise	30.00
6. Work of medium size held by one or two straps	30.00
7. Work of medium size held from turning on table by a stop in T-slot	15.00
8. Work of circular type such as washers, collars, bushings, and sleeves is held to table by a draw bolt through center	15.00

NOTE.—When tool lists for any of the above must be made out, an additional 15 min. are allowed. This is applied only to new jobs or when a new jig or fixture has been made.

Standard Data for Fundamental Elements.

It is evident that the jig used in drilling the one-inch adjusting screw, shown on the time-study sheet, can also be used for drilling many other sizes. The only factor that will vary in the drilling operation of the different sizes will be the time required to "drill the hole." Also, other jigs similar to the one used on this operation will have some fundamental elements that are identical. For example, the time to "pick up piece and place it in the jig" will be approximately the same for many kinds of shafts, screws, collars, and odd-shaped pieces, as long as the pieces are about the same size as to dimensions and weight. Tables can be made up from time studies to contain standard time elements as shown[1] on pages 133 and 134. If this information had been available, the time study in Fig. 78 would not have been taken. It would be a very simple matter to refer to Table XV, find that the jig used is that of class *A* and that the time required for chucking and removing the piece is 0.45 min. The time for machine manipulation is shown in Table XVIII and this is 0.07 min. So that the total handling time for the operation would be 0.45 + 0.07 = 0.52 min. If no table is available for the machine time (drilling time in this case), this element could be timed and added to the handling time. That means that the ordinary stop watch would be required to time the drilling element and then this time would be added to the handling time as taken from the tables. The sum would be the base time to which would be added the allowances to give the standard time for the operation.

With time-setting tables available as shown on the preceding pages, the time study would appear as follows:

Chuck and remove piece (from Table XV)...	0.45
Machine manipulation (from Table XVIII) .	0.07
DRILL ¼-IN. HOLE (actually timed as in Fig. 78)........	0.46
Selected operation time or base time	0.98
Allowances to be added = 10 per cent.......	0.098
Standard time for one piece...............	1 078 use 1.1

It is evident that considerable time and effort are saved by the use of the standard data and this at once leads to the idea of

[1] These tables have been developed and used successfully by the Gleason Works.

developing a complete set of tables and charts which will make it possible to build up the standard time entirely without any actual time study being made in the shop.

Use of Charts and Formulas in Setting Time Standards.

The use of standard data for determining handling time has been explained above. The machine time in an operation can very often be calculated, and particularly is this true when feeds and speeds of the machine are accurately maintained. For example, in the case of a milling machine with power feed, if the feed of the table is known in inches per revolution of the cutter,

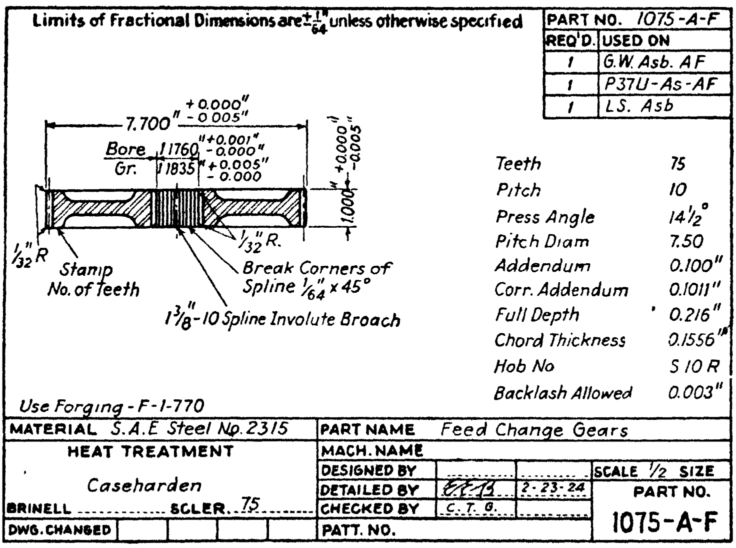


FIG. 80.—Detail drawing of a change gear, part 1075-AF.

and if the speed of the cutter is known in revolutions per minute, it is just a question of simple arithmetic to find the time required to mill a bar of a given length. An allowance must be made for the approach and overtravel of the cutter, but that can be calculated.[1] If a shaft of a given length is placed between centers in a lathe and if the speed and the feed are known, it is an equally simple matter to calculate the length of time required to make the cut across the shaft and so find the machine time. Therefore, to build up the standard time for an operation completely,

[1] LEE, M. A., and D. VANDEVATE, Time Setting in a Machine Tool Plant, *Ind. Management*, vol. 19, No. 3, p. 152, March, 1925.

charts and tables must be available for determining both the handling time and the machine time. The sum of these two, plus the allowances, will give the standard time for the operation.

In order to determine the standard time of an operation completely, the following information would be required:

1. Feed and speed charts for the machine similar to that given in Fig. 83.

2. Machine data giving the maximum and minimum sizes of work that the machine will take. Also instructions indicating the machine type or class that should be used for the operation to be performed.

1. Change gear:

Case *A*.—Cut off in automatic.... no web 

Case *B*.—Cut off stock with saw.. no web 

Case *C*.—Cut off stock with saw.. with web

Case *D*.—Drop forgings.......... with web 

Case *E*.—Cast iron.............. with web

Bores:
(*a*) Spline
(*b*) Round
(*c*) Square

FIG. 81.—Classification of spur change gear blanks.

3. A tabulated set of standard chucking methods, jigs, tools, and other equipment for holding the work.

4. A classification of all work that is performed on the machine such as shown in Figs. 81 and 82.

5. Time-setting charts, tables, or formulas for determining the handling time as shown in Fig. 84.

A standard must be determined for each of the different chucking methods, standard set-ups, etc. These, once having been made from time studies, need be recorded only in tabular or graphical form for convenient reference and use.

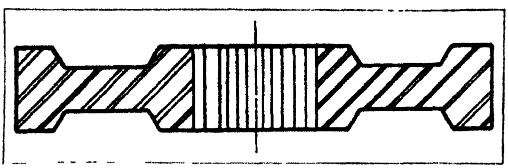
In order to make this whole idea more easily understood, it will be assumed that an order is received in the shop for 100

"change gears," as shown by the detailed drawing in Fig. 80. This problem of finding the standard time for turning the blank will show the use of standard data and formulas. The change-gear blank is to be 7.700 in. in diameter finished, and it will be made from a drop forging. All spur change gears that have previously been made in the shop have been classified into five standard kinds, as shown in Fig. 81. From this table it is seen

SPUR GEARS

Case *D*.—Drop forgings, with web

Material: S.A.E. 1020
S.A.E. 2315
S.A.E. 2320
Bore:
Round or
Spline



Outside diameter—4½" and over

Operation number	Operations (round bore)	Machine class	Time setting table
5 TR	Rough 1 side and ¾ of outside diameter.....	58	
10 TR	Bore, rough other side and ½ of outside diameter..................................	58	
15 BR	Broach bore..............................	64	
20 BR	Broach keyway..........................	64	
25 RE	Hand ream...............................	X	
30 TR	Face one side............................	60	
35 TR	Face other side and finish outside diameter...	60	
40 TR	Radius all corners.......................	60	
45 ST	Stamp number of teeth...................	X	

FIG. 82.—Operation sheet for spur change gear blank (Case *D*).

that the present gears to be made will fall into case *D*, since they are steel forgings with web. There is a standard operation or route sheet giving the procedure for machining the gears falling into each of the five classes. The operation sheet for case *D*, shown in Fig. 82, lists each operation to be performed in its proper sequence. The first operation is 5TR, "face one side, rough ¾ O.D." (O.D. meaning outside diameter). This work will be done in department 11 on a machine in class 58. Machine

J. AND L. DOUBLE-SPINDLE FLAT TURRET LATHES, Serial numbers—1052, 1113, 1114. Machine class 58

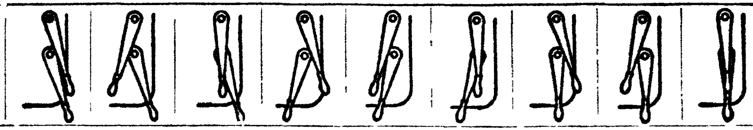
Diagrams showing clutch-lever positions (Speed of driving pulley 1,200 revolutions per minute)											Feet per minute
Spindle speeds—(approximate revolutions per minute)		301	202	145	111	75	54	39	27	19	
Screw-thread cutting		.....	.....	.....	.....	.....	5/8	1	1 3/8	1 13/16	10
		.....	.....	.....	.....	1 1/16	1 5/16	1 1/2	2	2 3/4	15
Turning speeds for high speed steel		5/8	13/16	1 1/8	1 3/4	2 1/4	3 3/16	4 7/8	6 5/8	9 1/8	50
		3/4	1 1/16	1 3/8	2 1/8	2 11/16	4 3/4	5 7/8	8	10 3/4	60
		1	1 3/8	1 7/8	2 11/16	3 9/16	5 1/8	7 3/4	10 1/2	14 1/2	80
		1 5/16	1 5/8	2 3/8	3 1/2	4 7/16	6 3/8	9 3/4	13 1/8	18 3/4	100
		1 5/8	2	2 15/16	4 7/16	5 9/16	8	12 1/4	16 1/2	......	125
		1 15/16	2 1/2	3 1/2	5 1/4	6 3/4	9 1/2	14 1/2	.....	......	150
		2 1/4	2 15/16	4 1/8	6 1/4	7 7/8	11	17	.....	......	175
		2 9/16	3 1/4	4 5/8	7 1/8	8 7/8	12 3/4	.....	.....	......	200
	Feeds per inch	Time required to travel one inch									
Turning feeds (for gear-feed machine)	20	0.07	0.10	0.14	0.18	0.27	0.37	0.51	0.74	1.1	
	30	0.10	0.15	0.21	0.27	0.40	0.56	0.77	1.1	1.6	
	40	0.13	0.20	0.28	0.36	0.53	0.74	1.0	1.5	2.0	
	48	0.16	0.24	0.33	0.43	0.64	0.89	1.2	1.8	2.5	
	55	0.18	0.27	0.38	0.50	0.74	1.0	1.4	2.0	2.9	
	71	0.23	0.35	0.49	0.64	0.95	1.3	1.8	2.6	3.8	
	81	0.27	0.40	0.56	0.73	1.1	1.5	2.1	3.0	4.3	
Drilling feeds	100	0.33	0.49	0.69	0.90	1.3	1.9	2.6	3.7	5.3	
	113	0.38	0.55	0.78	1.0	1.5	2.1	2.9	4.2	6.0	

FIG. 83.—Speed and feed chart for Jones and Lamson flat turret lathes.

class 58 refers to a Jones and Lamson two-spindle turret lathe. This job might have been done on either the J. & L. or a Warner and Swasey lathe, but from experience it is known to be more economical to do lots of 25 pieces or more on the J. & L. The set-up time and the tooling equipment available are the determining factors.

Figure 83 shows the speed and feed chart which will be used for this operation. The time-setting table is given for operation 5TR, case *D*, in Fig. 84. This table is a master time study made up from many time studies. By checking the base time

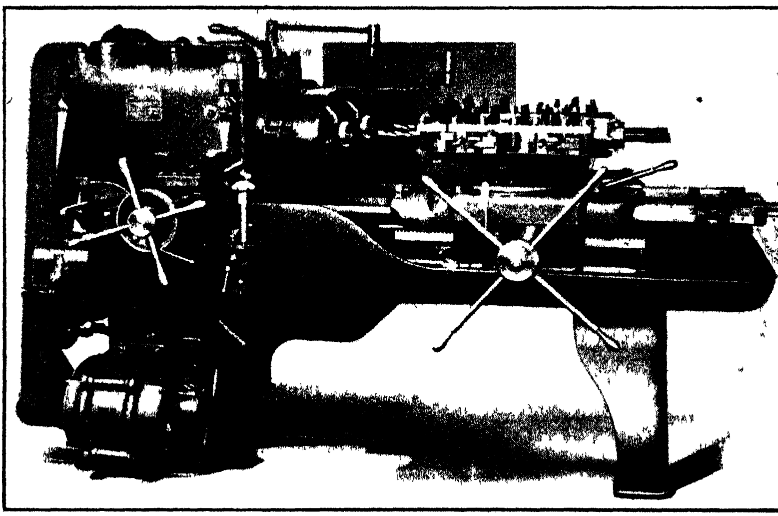


FIG 83*a* —Jones and Lamson flat turret lathe.

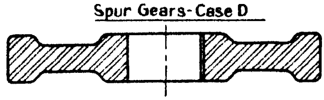
for turning blanks of different diameters, it was found that the machine time was the only variable. That is, the handling time was found to be practically the same for a blank 5 in. in diameter as for one 8 or 10 in. in diameter. So it can be said that the time-setting table in Fig. 84 gives in tabular form the proper sequence of elements, along with the time for each element. This table is correct for any spur-gear blank, under case *D*, regardless of its diameter.

There are two main divisions of the work: (1) set-up and (2) the actual operation. The set-up or preparation time is required for tooling the machine and arranging it in readiness to perform the operation. The standard time allowed for this is 60.00

min., as shown on the instruction sheet in Fig. 85. The set-up time was determined by time study. The actual operation is composed of two parts, namely the handling time and the machine time. By handling time is meant the time used in manipulating the machine and in placing and removing the piece from the machine, as distinct from the machine time, which is

TIME SETTING TABLE

Spur Gears-Case D



Material - S A E 2315 (drop forgings)   Machine Jones & Lamson 2 Spindle Flat Turret Lathe

Operation - 5 7R

Drill, rough 1 side and ¾ of O D

1 Setup Time

Std Time {60 min new setup; 30 min changing size only}

2 Handling Time

Operations	Aver depth of cut	Speed ft/min	Feed Setting	Feed In/rev	Time
1 - Pick up and chuck 2 pieces					.12
2 - Start machine and true up (if necessary)					10
3 - Change Speed					03
4 - Adv turret and throw in feed					06
5 - ROUGH O D (3/4)	1/8"	70	71	014"	M
6 - Back turret and index					07
7 - Adv turret, set headstock, throw in feed and change speed					12
8 - DRILL		60	71	014"	M
9 - Back turret and index					07
10 - Adv turret and lock					08
11 - Adv headstock, change speed and throw in feed					08
12 - ROUGH FACE 1 SIDE	1/8"	70	71	014"	–
13 - ROUGH FACE HUB	1/8"	70	71	014"	M
14 - Unlock, back and index turret					07
15 - Adv turret and set headstock					09
16 - CHAMFER INSIDE FLANGE		70	Hand	Hand	10
17 - Adv headstock					06
18 - CHAMFER HUB		30	Hand	Hand	10
19 - Back turret and index					07
20 - Set headstock					12
21 - Stop machine					.03
22 - Loosen and remove 2 pieces					10
Total handling time for 2 pieces					147

3 Cutting Time

Drill – Add 5/8" to finished dimension
Rough O D - Use 7/8 of finished dimension
Rough Face - Add 1/8" to finished dimension
Rough Hub - Add 1/8" to finished dimension

FIG. 84 —Time-setting table

the time that the machine is actually doing work on the piece, such as turning, boring, drilling, and the like. The machine time is indicated on the time-setting tables and on the instruction cards by capital letters, the first machine element being ROUGH O.D. ¾. If the speeds and feeds of the machine and the length of the tool travel are known, it is an easy matter to calculate

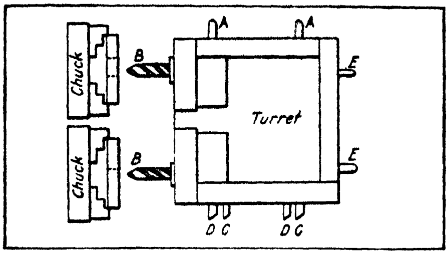
Instruction Sheet—Gleason Works

Part Name Spur gear Case D.	Customer Gleason
	Part No. 1073 A-F
Operation Name Drill, rough one side and ¾ of outside diameter	Operation No. 5 TR.

Dept. 11 Machine class, 58 Machine name, Jones & Lamson

Made by F. C. W. Approved by D. V. Date 7-9-25 Mat'l SAE 2315

Tool layout



Set-up Time:
New set-up: 60.00
Change of size 30.00

No.	Procedure	Tools—jigs, etc.	Speed Setting	Speed Ft./min.	Feed Setting	Feed In./rev.	Base time
1	Pick up and chuck 2 pieces						0.12
2	Start machine and true up (if necessary)						0.10
3	Change speed						0.03
4	Adv. turret & throw in feed						0.06
5	ROUGH OUTSIDE DIAMETER (¾)	A. ¾ × 1¼ in. tools		70	71	0.014	*2.32*
6	Back turret and index						0.07
7	Advanced turret, set headstock, throw in feed & change speed						0.12
8	DRILL	B. 1¾₆ in. drills		60	71	0.014	*0.58*
9	Back turret and index						0.07
10	Advanced turret and lock						0.08
11	Advanced headstock, change speed and throw in feed						0.08
12	ROUGH FACE 1 SIDE	C. ¾ × 1¼ in. tools		70	71	0.014	*1.65*
13	ROUGH FACE HUB	D. ¾ × 1¼ in. tools		30	71	0.014	
14	Unlock, back and index turret						0.07
15	Advanced turret and set head stock						0.09
16	CHAMFER INSIDE FLANGE	E. ¾ × 1¼ in. Form tools		70	Hand		0.10
17	Advanced head stock						0.06
18	CHAMFER HUB	E. ¾ × 1¼ in. Form tools		30	Hand		0.10
19	Back turret and index						0.07
20	Set head stock						0.12
21	Stop machine						0.03
22	Loosen and remove 2 pieces						0.10
	Total handling time for two pieces						*1.47*
	Total machine time for two pieces						*4.55*
	Total base time for two pieces						*6.02*
	Total base time for one piece						*3.01*
	Allowances 10 per cent						*0.30*
	Standard time in minutes per piece						*3.31*

Fig. 85.—Instruction sheet.

the time that the machine element will consume. The time-setting table gives the handling time; the machine time can be calculated; and the sum of these two will give the base time. To this base time allowances will be added for fatigue, personal needs, delays, etc., and the sum will be the standard time.

Calculations for the Machine Time for Operation 5TR.

Element 5 (*see Fig.* 84), *ROUGH O.D.* ¾.

$$\text{The cutting time in minutes} = \frac{\text{length of cut}}{\text{R.p.m. of work} \times \text{feed of tool}}. \quad (1)$$

The face of the blank is 1 in. when finished (from drawing, Fig. 80). Because of the method of chucking, only three-fourths of the face can be turned in this operation. Since the forging is rough, it is found that the length of travel of the tool will be seven-eighths of the finished dimension (see note at the bottom of Fig. 84). Therefore, the length of cut will be seven-eighths of the face or ⅞ in. The table shows that the speed of the work in feet per minute should be 70 (see Fig. 84). This speed has been determined from many experiments and has been found to be correct. The speed of the work in revolutions per minute is proportional to the linear speed in feet per minute. Or:

$$\text{R.p.m.} = \frac{\text{feet per minute}}{\pi \times \text{diameter of work in feet}}$$

$$= \frac{70}{3.14 \times 0.642\ (0.642 = 7.7 \div 12)} = 35.$$

These above computations may be made very quickly by the use of a speed slide rule. Referring to the speed and feed chart in Fig. 83, the next lower speed at which it is possible to run the machine is 27 r.p.m., so this speed will be used. If the next higher speed were used, that of 39 r.p.m. in this case, it would probably be too fast and the tools might not stand up under it. The feed to be used is indicated in the time-setting table as 0.014 in. per revolution of the work. Solving Eq. (1) for the cutting time:

$$\text{Cutting time} = \frac{0.875}{27 \times 0.014} = 2.32 \text{ min.}$$

This means that the cutting time of 2.32 min. is required to turn three-fourths of the outside diameter of the gear blank.

Element 8, *DRILL.*—Equation (1) for the cutting time may be used in calculating the drilling time. The cutting time will now be the drilling time. Because of the V-shaped point of the drill and because of the rough nature of the surface of the forging, $\frac{5}{8}$ in. is added to the finished dimension. The length of cut will be 1 in. + $\frac{5}{8}$ in., which is 1.625 in. The revolution per minute of the work is determined as before, using 60 ft. per minute as the surface speed of the drill, and the diameter of the drill used is listed in the center column of the instruction sheet in Fig. 85 as $1\frac{3}{16}$ in.

$$\text{R.p.m.} = \frac{60}{3.14 \times (1.1875 \div 12)} = \frac{60}{3.14 \times 0.099} = 193 \text{ r.p.m.}$$

From the speed and feed chart of the machine (Fig. 83) the nearest speed is 202 r.p.m., which is only slightly higher, and this will be used. The feed of 0.014 will be used. Solving Eq. (1) for the cutting time:

$$\text{Cutting time (in this case drilling time)} = \frac{1.625}{202 \times 0.014} = 0.58 \text{ min.}$$

At the above speed and feed it will require 0.58 min. to drill the $1\frac{3}{16}$-in. hole through the gear blank. It will be noted from Fig. 85 that the work turns and not the drills.

Element 12, *ROUGH FACE ONE SIDE.*

Element 13, *ROUGH FACE HUB.*

These two operations are done together and it is necessary to calculate only the longer cut, which is element 12, *rough face one side.* This is apparent from the drawing. These dimensions are not shown on the drawing but they will be scaled. This gives the length of the cut as $\frac{1}{2}$ in., but from the note on the time-setting table (Fig. 84), $\frac{1}{8}$ in. will be added to this dimension so that the actual length of cut to be made will be 0.625 in. The speed of the work is 70 ft. per minute, and this, as calculated before, gives 27 r.p.m. The speed as before is 0.014 in. per revolution. Solving Eq. (1) for the cutting time:

$$\text{Cutting time} = \frac{0.625}{27 \times 0.014} = 1.65 \text{ min.}$$

Element 16, *CHAMFER INSIDE FLANGE, and* 18, *CHAMFER HUB.*—These two elements are also machine times, but they

are of such a nature that standard time has been determined for them and is recorded on the time-setting table, along with the handling times. The total of the handling time along with these two small machine operations appears at the bottom of the time-setting table (Fig. 84) and is equal to 1.47 min. for two pieces.

Element 5, ROUGH O.D. ¾	2.32	
Element 8, DRILL	.58	
Element 12, ROUGH FACE ONE SIDE	1.65	
Total machine time	4.55	
Total handling time	1.47	
Total base time for two pieces	6.02	
Total base time for one piece	3.01	3.01
Allowance 10 per cent		.30
Standard time in minutes per piece		3.31

The standard time for operation 5TR is 3.31 min. In a like manner, the standard time for the remaining operations could be found. With the aid of a slide rule and a speed rule it requires but a few minutes to make the calculations.

The above charts and tables have been worked out at the Gleason Works, and their use over a period of several years has given satisfactory results.

Charts and tables are now used in determining time standards for work of widely varying nature such as punch-press operations, drilling, spiral bevel-gear cutting, gear hobbing, cutting cams for automatic screw machines, thread milling, etc.

Time Study and the Worker.

The attitude of the time-study observer in dealing with the worker has an important bearing on the success of his work. It is essential that he secure the cooperation and friendship of both the employees and the supervisors. The time-study department should be directed in such a manner that the personnel of the entire plant will have confidence in its work.

Time standards may be set accurately, but to be of value the worker must be taught to perform the operation in the time set. This requires tact, patience, and absolute honesty on the part of the time-study observer. Once the employees learn that they

will be dealt with in a fair and reasonable manner, the time-study observer will find his task much pleasanter and his work more satisfactory.

In order to give an illustration of the worker's reaction to the making of a time study, the following case is included:

"The accompanying chart (Fig. 86) illustrates the attitude of one worker toward time studies made with the view of setting tasks. Here the work was done by a girl and was purely a hand operation.

"It consisted in gaging and straightening a slim drop-forged bar about 5 in. long. The bars had to be straight, and a hole in one end fitted accurately over a pin. The operator used a

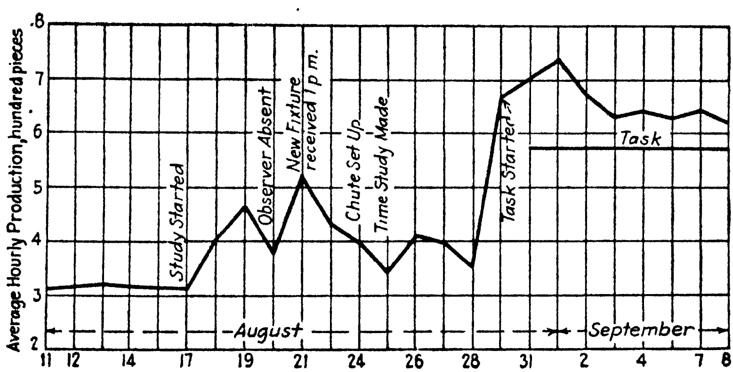


FIG. 86.—Chart showing the effect of time study on the worker's output.

special gage fastened to the bench and a pair of three-prong pliers to bring the hole in the bar in line with the pin in the fixture.

"The girl took a handful of bars from a box on the floor and placed them beside the gage. She then straightened and gaged the work, putting the finished pieces on her bench. When a handful of bars was completed she transferred them to a tote pan. Prior to the study her production was uniform at about 310 pieces per hour. She received 8 cts. per 100 pieces, so her earnings were 24.8 cts. per hour.

"The time-study man arrived on the job on Aug. 17 at 1 p.m. For that day her average production was unchanged. The following day, under the guidance of the time-study man, her production rose to 400 pieces per hour and the next day to 460 pieces. She was helped to attain the latter figure by the installa-

tion of a chute built from the bench to a large tote pan on the floor for the removal of the finished work.

"The observer made a sketch of a hopper into which a full day's work could be placed and which fed the bars down a chute to a convenient place in front of the fixture. He also ordered a new fixture made. On the following day he was absent, and production fell to 385 pieces per hour. The next day, under the coaching of the observer and the receipt of a proper fixture, her production rose to 515 pieces per hour. Then, being alone on the job and apparently frightened by her big production, she fell off to 430 pieces per hour. On this last day, however, workmen were setting up the new hopper and chute and probably interfered with her to some extent. The afternoon of the following day a time study was made of the operation, and production fell to 350 pieces per hour, being only slightly over her old average.

"During the next 3 days the observer figured up the task. It was set at 560 pieces per hour, and a bonus of 25 per cent was approved for its accomplishment.

"On Aug. 30, under the coaching of the observer, the task was put into effect, and the girl, anxious to accomplish it, worked hard all day, turning in an average of 660 pieces per hour. For the next 2 days she averaged 700 and 730 pieces per hour. Then as the strain of the new incentive wore off, she settled down to an average production of 610 pieces per hour. This average was consistently maintained and represents a good day's work that kept her interested and happy and produced no excessive fatigue. For accomplishing the task her wage was 31¼ cts. per hour and for her average production of 610 pieces per hour she received 34 cts. per hour. On her peak day she made 40.7."[1]

[1] UNDERWOOD, CHARLES N., Good Work Habits, *Factory and Ind. Management*, vol. 78, No. 6, p. 1335, December, 1929.

CHAPTER VIII

TIME AND MOTION STUDY. THE MOTION-PICTURE CAMERA AND MICROMOTION STUDY

Motion study does not necessarily require the use of a motion-picture camera, but for many kinds of work this equipment is almost indispensable. Motion pictures not only aid in finding the best method of doing the work but they also show the elemental time intervals for each of the operations studied regardless of the length of the element.

Fundamental Motions.

A complete analysis of the motions of an operator or a machine is made possible through the use of the motion-picture camera. The entire operation can be recorded permanently on the film and by the use of a projector it can be reproduced on the screen when desired. Furthermore, the motions can be examined in great detail on the film itself. It is often desirable to project a single frame or a few frames on the screen, as this makes it easier in many cases, to study the motions shown by the enlargements.

Various attempts have been made to set up a system of fundamental motions to be used as the basis for analyzing any operation or cycle of motions. The Gilbreth set of 17 elements is shown in Table XX, and the use of these elements will be explained later.

Other users of the motion-picture technique for analyzing motions have concluded that all possible fundamental movements can be divided into seven groups[1] as follows:

1. *Observation*, which includes all fundamental movements denoting the imparting of a sensation.

2. *Grasping*, comprising the fundamental movements which establish junction or separation between a part of the body and an object.

3. *Movements in space*, *i.e.*, movements of a part of the body which are not directly connected with the object.

[1] Grillo, Signor, The Contribution of the Cinema to Time Studies, *Internat. Rev. Educ. Cinematography*, p. 896, July-August, 1930.

Table XX.—Gilbreth Symbols and Colors for Simultaneous Motion Cycle Charts

Name of symbol	Mnemonic symbol for Therblig	Explanation—suggested by	Color
Search		Eye turned as if searching	Black
Find		Eye straight as if fixed on object	Gray, heavy
Select		Reaching for object	Gray, light
Grasp		Hand open for grasping object	Lake red
Transport loaded		A hand with something in it	Green, heavy
Position		Object being placed by hand	Blue, heavy
Assemble		Several things put together	Violet, heavy
Use		Word "use"	Purple
Dis-assemble		One part of an assembly removed	Violet, light
Inspect		Magnifying lens	Burnt ochre
Pre-position for next cycle		A nine-pin which is set up in a bowling alley	Sky-blue, light
Release load		Dropping content out of hand	Carmine red
Transport empty		Empty hand	Green olive or light
Rest for overcoming fatigue		Man seated as if resting	Orange
Unavoidable delay		Man bumping his nose, unintentionally	Yellow ochre
Avoidable delay		Man lying down on job voluntarily	Lemon yellow
Plan		Man with his fingers at his brow, thinking	Brown

Courtesy of L. M. Gilbreth.

4. *Displacement,* movements of the body in direct connection with the movement of an object or which result in such movement.

5. *Rest,* signifying the absence of any movement relating to the work.

6. *Change of position,* which groups together all movements which determine a fresh position of the body.

7. *Handling of tools, i.e.,* movements necessary to the manipulation of tools or the handling of machine tools.

Classification of Motions.

In the micromotion study work at the General Electric Company, R. M. Blakelock divides all hand motions into five general classes:

1. Finger motions.
2. Motions involving fingers and wrist.
3. Motions involving fingers, wrist, and forearm.
4. Motions involving fingers, wrist, forearm, and upper arm.
5. Motions involving fingers, wrist, forearm, upper arm, and shoulder. (This class necessitates disturbance of posture.)

"These general classifications are given in progressive order, the first class requiring the least time and effort. It is fundamental, therefore, that motions should be confined to the lowest classification with which it is possible to perform the work properly."

Motion Study and the Work Place.

"Proper placing of materials and tools at the work place is highly important, and the rules governing this factor give the analyst a definite approach to the problem of setting up the work place. Considering the horizontal plane, there is a definite area within which materials and tools should be placed so that they may be handled and the work performed with a normal expenditure of energy. The area for the right hand will be indicated by an arc drawn with the right arm fully extended in front, making one sweep across the table, pivoting from the shoulder. The area for the left hand is likewise indicated by extending the left arm forward and pivoting from the left shoulder. These two areas are termed the maximum working area, beyond which it is possible to use only fifth-class motions—the least desirable classification. These are again divided into two areas termed normal working areas which are indicated by arcs drawn in the

same manner, but with only the forearms extended, the upper arm being more or less relaxed and the elbow close to the body until the end of the movement is approached, when the elbow follows the natural inclination to swing away. It is desirable, therefore, to locate materials and tools within the normal working area, and with respect to the lowest classification of motions permitted by the character of the work.

"Figure 87 shows an example of motion study applied to small assembly work. Duplicate trays for holding supplies of the materials are provided on either side of the operator to allow a

FIG. 87.—Work place for the assembly of small parts.

proper distribution of motion between right and left hand. The trays are inclined at an angle of about 25 deg. to allow the parts to slip forward as they are used from the front portion of the trays. In this arrangement, all the parts used are located within the maximum working area. The operator may reach any part of this working area without disturbance of posture. Forty-four parts are included in this assembly, twenty of which are screws, each screw requiring a plain washer and a lock washer. The screws are driven by a foot-operated power screw driver."[1]

Use of the Motion-picture Camera.

There are two methods of indicating time on the motion-picture film. First, by the use of a rapidly moving clock (called

[1] BLAKELOCK, R. M., Micromotion Study Applied to the Manufacture of Small Parts, *Factory and Ind. Management*, vol. 80, No. 4, p. 730, October, 1930.

microchronometer) placed in the range of the camera while the pictures are being made. This method was developed and used by F. B. Gilbreth. The advance in the position of the clock hand from one frame to the next shows the time interval; time elements may be read to 1/2,000 min. The ordinary hand-cranked 35-mm. motion-picture camera or the spring-driven 16-mm. amateur camera may be used. The Gilbreth method of micromotion study is illustrated by the following example:[1]

"Motion study is a method of analyzing work in order to eliminate needless, ill-directed, and ineffective effort, and the resulting unnecessary fatigue, and to utilize the necessary effort in the most economical way. It benefits the worker by placing the best-adapted worker on the job, by eliminating fatigue, and by increasing earnings; it benefits the employer by increasing production and decreasing unit costs; and it benefits the community by providing lower-priced commodities, greater purchasing power, and better-adapted and better-satisfied members of society.

Method and Technique of Motion Study.

"'Motion study consists of dividing work into the most fundamental elements possible; studying these elements separately and in relation to one another; and from these studied elements, when timed, building methods of least waste.'[2] 'The variables which must be studied in analyzing any motion, group themselves naturally into the following divisions: (1) variables of the worker; (2) variables of the surroundings, equipment, and tools; (3) variables of the motion.'[3] 'The accurate measurements involved in getting the best results include three elements. We must determine first the units to be measured; second, the methods to be used; and, third, the devices to be used.'[4] These devices should be as refined as necessary to get the best results, considering also how much time and money may be justified by the expected results.

[1] LIES, B. EUGENIA, and MARIE P. SEALY, Motion-study Principles and Their Application in a Department Store, *Trans. A.S.M.E.*, vol. 50, No. 29, Man-50-17A, p. 21, Sept.–Dec., 1928, reproduced by permission of the authors.

[2] GILBRETH, F. B. and L. M., "Applied Motion Study," p. 48.

[3] *Ibid.*, pp. 6 and 7.

[4] *Ibid.*, p. 44.

"The method employed by motion study includes, first, recording present conditions and practice. Under 'conditions,' the survey includes the surroundings of the worker, such as the lighting, ventilation, dust, temperature, humidity, odors, noise, etc. The work place and its relation to the worker are also studied, that is, the equipment used, such as desk or bench, chairs, etc., and also the tools and devices used. The work done is recorded in detail. For this purpose the process chart is used, and, in some cases, micromotion study. Both of these devices and their uses are discussed later in detail.

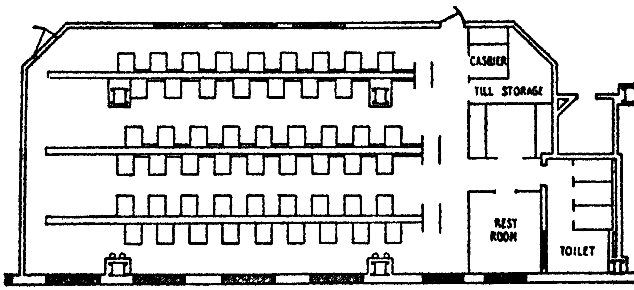


FIG. 88.—Layout of tube room.

"All other data relating to the job such as flow of work, peaks in business, records of past production, cost records, etc., are also gathered, as well as data concerning the worker, including the physical, psychological, and psychiatric factors influencing his work on the job. Information on age, sex, schooling, physical conditions, and personality traits and ratings on intelligence and psychological tests are included in the worker's record.

Other Steps of Method.

"After present conditions and practice have been recorded, the next step is to analyze the data, considering such points as the following:

1. Is the work necessary? Does it contain any unnecessary elements, operations, or 'therbligs?'[1]
   a. Can these be eliminated entirely because they are useless?
   b. Can they be eliminated by combination, substitution, etc.?
2. a. Can the necessary work be done with less expenditure of effort?
   b. Is the arrangement of work, materials, and tools within the normal grasp area?

[1] Gilbreth divided all operations into 17 elements of a cycle of motions which he called "therbligs" (see Table XX).

c. Is the routing and scheduling most direct, providing continuous work, etc.?
d. Can improvements which will reduce fatigue be made in the surroundings of the worker?

"Through the analysis of the data, possibility methods are developed, and finally the ideal solution is determined, including the best methods, the best conditions, and the best type of worker. However, the ideal solution may not be the one actually installed, since limiting factors, such as the cost of new equipment compared with possible savings, may force deviations from the ideal. The solution decided upon, however, must be the best practical solution, considering all of the factors in the situation. Developing the ideal solution is, however, desirable and essential even though it may not be installed *in toto*.

"After the conditions and methods are standardized, the task can be set and an incentive plan decided upon. Then the problem of maintenance of the standard methods always arises, and for this purpose standing orders and instruction cards are used.

Devices Used Depend upon Problem.

"When the motion-study analyst is beginning an investigation, he decides how much and what elements of his technique he must use on the particular job. The character of the job decides this question. At times only a process chart will be necessary. On other more complicated jobs a micromotion study involving the use of motion pictures may be needed.

Process Charts.

"Process charts are used to record in a simple, compact form and to visualize the elements of a process in sequence and in relation to the entire process. They record present practice for the purpose of studying and analyzing the present practice and also serve in visualizing possibility processes which improve the present practice by (1) changing the sequence of elements, (2) eliminating elements, (3) combining elements, and (4) substituting or changing elements.

"As a record of standard practice, the process chart serves as an authoritative and complete picture of the entire process. It is particularly useful as a teaching device and as a means of maintenance.

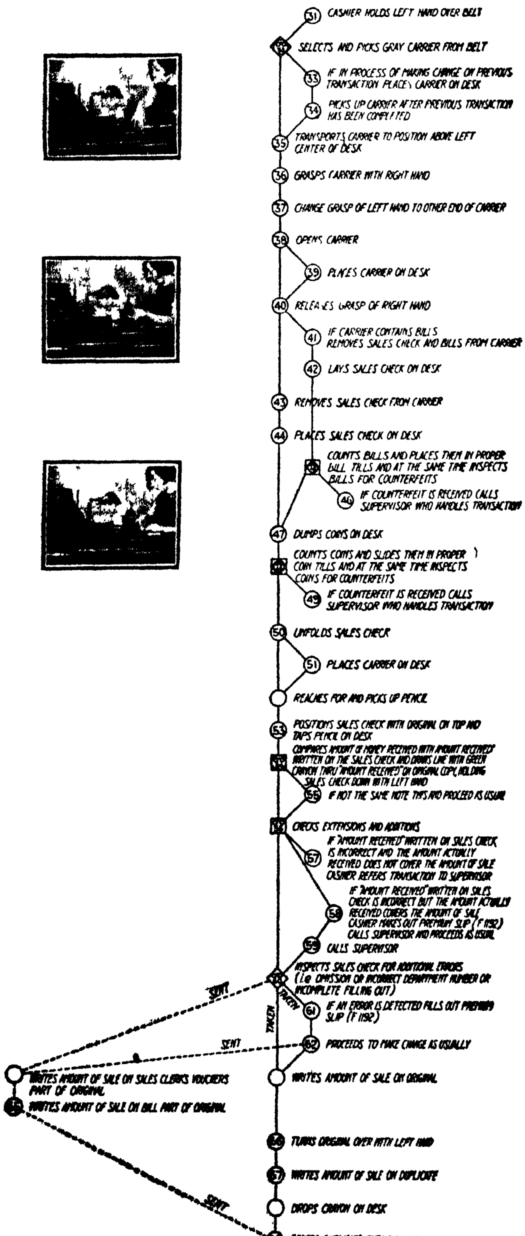


FIG. 89.—Portion of process chart including some of the operations performed by the cashier.

"At the top of a process chart there is usually a plan of the work place, with the arrangement of equipment and tools. The chart itself is made up of a series of symbols, connected by lines, indicating the sequence of operations and also the relationship of those operations, such as alternatives of process, separation of units, and combination of units. Such a chart, prepared in connection with the case illustrated in this paper, will be found in condensed form in Fig. 89. The symbols indicate:

1. What—that is, materials and supplies, operation inspection, movement, storage of materials and supplies.
2. How—that is, word description next to symbol.
3. Who—name of job or mnemonic job symbol.
4. Where—work places, work rooms, etc.
5. When—that is, sequence or if a definite time, in description next to symbol.

The why element is obtained by the analyst in his study of the chart.

Micromotion Study.

"The other particular device used by the motion-study analyst is the micromotion study. By this method, a motion picture is taken of the worker at his work place with a clock included in the picture. A record is thus made of the method used, the time taken, and all the surrounding conditions (except sound).

"The data on the film may be studied at any convenient time and shown graphically on a simultaneous motion-cycle chart, known as a "simo" chart, a sample of which is illustrated in Fig. 90. Such a chart indicates horizontally the parts of the body used and vertically the time consumed by each element of motion or therblig. The time is shown in units of 1/1000 min., which is possible because the clock included in the picture registers time in this small unit. As the data are taken from the film, the motions are split up into therbligs. Each of the 17 therbligs is shown in an individual color, so that it is possible to see from the chart the exact therbligs used and the time consumed by each.

"By comparing the therblig analyses of all the methods used, the analyst can easily compare the differences in the various methods and can evaluate each. He is then able to complete his analysis and synthesize the best arrangement of therbligs into the best method.

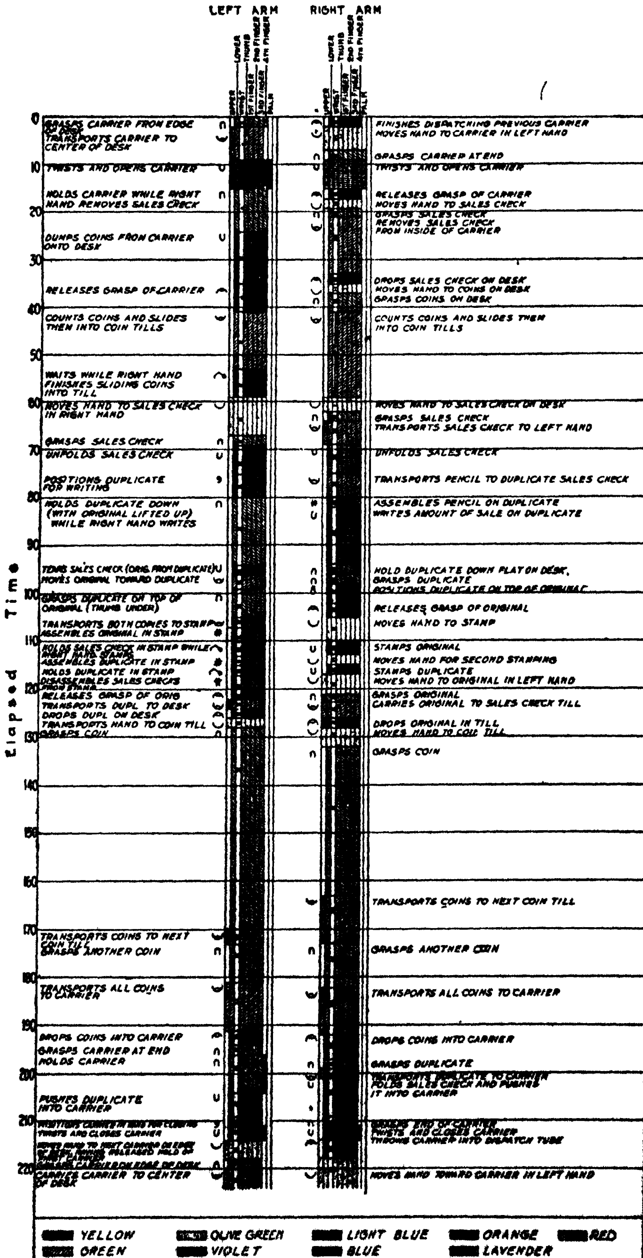


FIG. 90.—Simultaneous motion-cycle chart.

Value of Motion Study.

"Analyzing work by means of the principles and technique described above has the following advantages:

"1. In the first place, this method considers every element influencing the work and thus effects improvements in every factor, that is, the surroundings, the equipment and tools, the method, the worker, and thus the time.

"2. Motions are recorded as well as time, and thus the data on time are of real value.

"3. In addition, this is the only method by which it is possible to analyze adequately operations involving short cycles or very rapid movements, since the elements of this type of work cannot be studied so accurately by the stop-watch method. Analyzing this type of work is very important, as often enormous savings can be made both in unit cost and in fatigue by analyzing these short-cycle or rapid-movement operations.

"4. These devices are also valuable in studying a group of workers. It is, indeed, the best method to record what each worker is doing simultaneously when a group works jointly on an operation.

"5. This method also has a decided advantage in recording the standard method as well as standard time. This is particularly valuable in setting a task.

"6. As a means of training the analyst himself, this method forces attention on all phases of a problem, develops a logical analysis of the job, and also develops keen observation in the elements of motion.

"7. This method also permits recording times of fundamental motions or therbligs. This is important in building up standard times, when the elemental times are considered in relation to the variables.

"8. As a means of training the worker, the micromotion produces acquisition of skill in a minimum time: first, by training in motions and thus developing habits of correct motions from the start; and, second, by providing a visual record of what is to be done.

Application of Motion Study in Retail Field.

"Turning to a definite field, we find that the principles of motion study can be applied in the retail or distributing field as

well as in the factory. This has, indeed, been done by R. H. Macy & Co., Inc., a retail department store in New York City, in order to perfect methods and systems and to set tasks.

"The technique, moreover, has been used on a large variety of jobs. It was used, for example, in analyzing conditions existing in the fur-storage department which receives coats from customers in the spring, stores them in cold vaults, and then delivers them to customers when wanted, usually in the fall. The entire work of the department is concentrated in a few weeks in the fall and spring. The fur-storage problem was largely one of determining the simplest, most direct, and most economical routing for the handling of the furs and the records involved; scheduling the work to take care of a tremendous peak, which lasts only a few weeks; providing the best methods for each job so that high production can be made on each job and, in addition, so that definite training can be given and the duties of each job learned in a minimum time.

"The method has also been used in the furniture warehouse, in arranging stock in some of the selling departments, and in standardizing methods and setting tasks in correspondence, typing, and depositors' accounts (banking) departments. To illustrate the principles of motion study, the details of the method as applied to the analysis of the problems existing in the central cashiers' department will be presented.

"The study of the cashiers' department was undertaken in order to improve the service to customers and also to decrease the operating costs of the tube rooms by increasing the production of the workers.

Description of Department and Work.

"The tube rooms are the units of a centralized cashiering system to which the money received from the customer and two copies of the sales check are sent in carriers via pneumatic tubes. The carriers fall on a belt conveyor and are carried to the cashiers who sit at desks on either side of the belts. Figure 88 shows the arrangement of one of these tube rooms.

"The cashier grasps the carrier from the belt, opens it, withdraws the money and sales check from the carrier, counts the money and checks the arithmetic of the sales check, stamps both copies of the sales check, retains one copy, but places the other with the change in the carrier. She then dispatches the carrier

by placing it into a tube from which it falls on to a lower belt conveyor which carries it to the switcher at the end of the belt.

"The switcher sends the carrier back to the department where it is given to the sales clerk. In the meantime, the merchandise checker, located in the department where the sale was made, has been wrapping the package, so that both the package and the change are now ready for the sales clerk to give to the customer.

Conditions before the Study.

"Before the study was made, a bonus plan had been in operation in the tube rooms for several years. With this incentive, an increase in production had been obtained. Indeed, some of the cashiers had become very skilled in methods which each one had developed for herself and had developed a high average production. The average production of most of the cashiers was quite low, however, and the time required for a new cashier to become skilled was from 3 to 4 months. This was a decided handicap at the time of the Christmas peak, because there was a possibility of giving very poor service to customers unless new cashiers were hired long before the peak actually arrived.

Recording Present Conditions and Practice.

"The first step in the study was to record present conditions and practice. A survey of the surrounding conditions included the lighting, ventilation, noise, and vibrations.

"Desk lamps on each cashier's desk illuminated part of the working area of the desk as much as 50 ft.-candles (directly under the lamp), with variations down to 20 and 10 ft.-candles on different parts of the desk. The general illumination of the room, however, ranged around 4 ft.-candles, with parts of the room, especially the end and the corners, in deep shadows. The contrast between the brilliantly lighted spots on the desks and the meagerly lighted surroundings made the cashier adjust her eyes to the difference every time she raised or lowered them. This situation contributed to the fatigue of the cashiers.

"The ventilation was good in all of the tube rooms except the one nearest the street. Here the dust from the street was so bad that it was out of the question to keep the windows open.

"Nothing had been done to eliminate the noise caused by the vibrations of the air drums of the tubes and the whirring of the motors moving the belts. The noise was deafening, so much so

that the ringing of the telephone, which was almost continuous, was scarcely heard.

"The vibration of the floor of one of the tube rooms presented a very annoying problem. This tube room is over the engine room, in which the steam pipes were hanging from the ceiling directly under the floor of the tube room. The result was a constant quivering of the floor to which it was difficult to become accustomed.

"The general layout and routing of work in the tube rooms had been previously studied, and after restudying the situation, it was decided that the present layout was the most desirable one.

Work-place Equipment.

"The work place and the equipment, however, were also studied in detail. The layout of the desk was studied in connection with the motions involved in the transaction, as will be discussed later. The old desks were 38 in. high, a little too high for comfortable working when the cashier was standing, but the desks were made that height to accommodate the height of the top belt. High chairs were used also, but these were of the swivel type on which the seat and back rest tilted backward and on which a circular hoop about 10 in. from the floor served as a foot rest. The chair was so awkward that the cashiers sat only on the front edge, with no support for the back and in a very strained and fatiguing position. The equipment—the cashier's stamp, the carriers, crayon pencil, etc.—was also studied.

Record of Work Done.

"The work done in handling a tube-room transaction was recorded by means of a process chart, a portion of which is shown in Fig. 89. The entire process was recorded from the point at which the sales clerk writes the sales check and receives the money from the customer, and the transaction is followed through the work done by the merchandise checker and sales clerk until the change and package are handed to the customer. The complete process was thus charted in order to avoid the danger of later making changes in the cashier's work which would interfere with the work preceding or following the cashier's operations.

"The operations most directly relating to change making, that is, the operations of the cashiers, were studied more closely by means of the micromotion film.

"Motion pictures were taken of five cashiers. In order to determine which cashiers were to be filmed, the motions of all cashiers were observed and the psychological factors influencing their work were considered, as well as their production over a period of 6 months. All of these factors were considered in deciding upon the cashiers to study, and therefore the cashiers studied were not necessarily those with the highest production or the speediest motions, unless at the same time their motions were obviously good or particularly interesting.

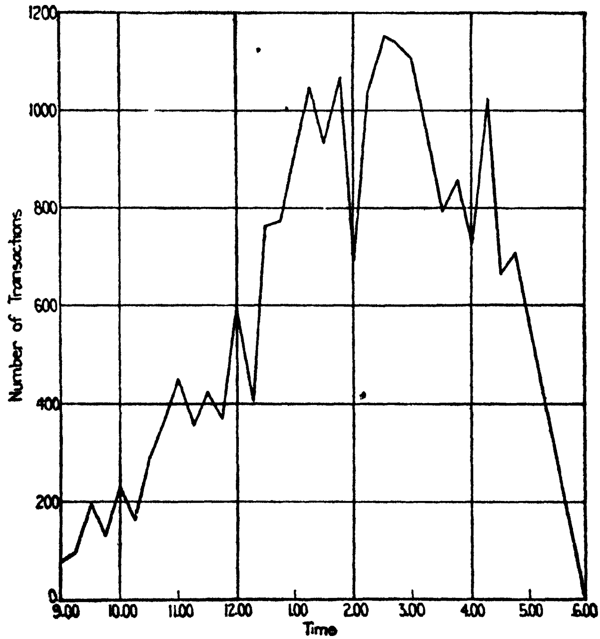


FIG. 91.—Hourly number of transactions in "B" tube room, Saturday, Mar. 26, 1927.

"The films were carefully analyzed both as to the motions used by the individual cashiers and also as to the relation of the work-place layout and the tools to the motions and variables of the cashiers. The cycles or complete transactions which showed differences in method, the use of fewer or more therbligs, the variables in the work, etc., were analyzed on simo charts. Twenty or more simo charts were made, one of which is shown in Fig. 90. Since different colors indicate the different therbligs, the different charts show clearly the variations in the therbligs used and also in the length of time spent on each therblig.

Other Data Relating to Work.

"Other data relating to the cashiers' work included information on the flow of business in the tube rooms. Figures 91, 92, and 93 show the peaks in the tube-room business. Statistical data on the cost of operations of the tube rooms were also studied. Time studies were made of the cashiers to find the average time required per transaction, and, from the customer's point of view, studies were made on the selling floor of the time required to get change. These data were collected in order to have all

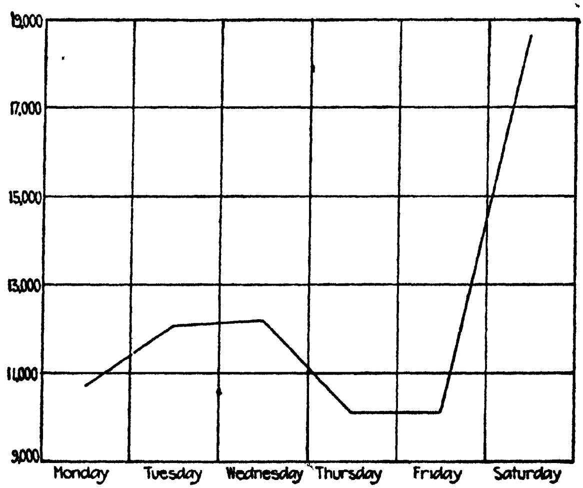


FIG. 92.—Total number of transactions in "B" tube room, Mar. 21 to 26, 1927.

data bearing upon the situation which were essential for complete analysis, as well as records of the "present" situation, so that comparisons could be made after changes had been determined upon and installed.

Physical and Psychological Analysis.

"Each cashier was given a physical examination and various psychological intelligence and performance tests. A psychiatric analysis was also made, including personality traits, home conditions, schooling and training, age, etc., to discover the factors tending to affect the success of the cashier in this kind of work.

Analysis of Present Practice and Improvements.

"All data on present conditions, methods, and workers were then analyzed with the cooperation of the supervisors of the tube

rooms and the cashiers themselves, all of whom considered the findings and the suggested change. Possible changes in the tube-room methods were considered in relation to the effect on the elements of the operation preceding and following.

"For example, an analysis of the simo charts showed that from 27 to 34 per cent of the total time required to handle a transaction was required to write on and stamp the sales check. The cashier, as already explained, checked the extensions and additions of the sales check. After doing this she had to write the total amount of the sale on both copies of the sales check, the theory being that from a psychological point of view the cashier was forced to observe the amount of the sale carefully and also that, in cases of dispute with the selling floor or the audit as to the amount of change given, the cashier's notation on the sales check would prove her interpretation of the sales check. The question then arose: Even so, was this writing necessary? And if so, was it necessary to write the amount on both copies of the sales check? After investigation, it was decided to retain the writing on one copy of the sales check but to eliminate it from the other copy.

"Analyzing the methods of writing, it was found that one cashier held her pencil throughout the transaction, whereas all the others dropped theirs after the writing in one cycle and picked it up again when ready to write in the next cycle. The simo charts showed that the cashier who held her pencil used fewer therbligs at this point and also that these therbligs which were eliminated helped her to perform this part of the transaction much more quickly than the other cashiers could. In fact, in some cases the pencil dropped back into the bill tills and then a "search" therblig was necessary in addition to a longer "transport empty" and "transport loaded" and to the "grasp" therblig. Experimenting with one cashier who had otherwise worked out excellent motions for herself, it was proved that after she had broken her habit of dropping the pencil and had established the new habit, her time for the operation was reduced, and that holding the pencil through the rest of the cycle did not prove a hindrance.

"Two particularly bad features were obvious in the layout of the desk. First, the box in which the cashier put the copy of the sales check which she retained was at the upper left-hand corne of the desk. The cashier stamped both copies of the sales check

with the stamp, located on the lower right-hand corner of the desk, and then carried her copy of the sales check to the box, diagonally across the desk, the longest distance. It was desirable to keep the stamp on the right-hand side for ease in stamping with the right hand, but the sales-check box was relocated directly under the stamp so that one copy of the sales check is dropped into the box as it is withdrawn from the stamp. Eliminating this long "transport loaded" and "transport empty" in the cycle reduced fatigue.

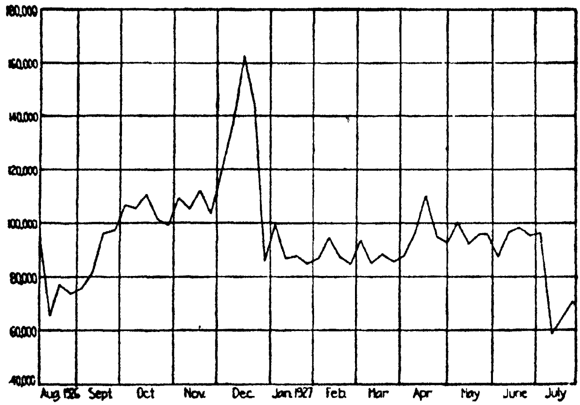


Fig. 93.—Weekly total transactions handled in basement tube room, Aug. 1, 1926, to July 31, 1927.

"Another improvement in the desk was the relocation of the dispatch tube which had been behind the desk at the side next to the belt, so that the cashier had to turn partly around to reach it easily. Also, the mouth of the tube was very little larger than the carrier so that the carrier had to be positioned very carefully when dispatching it. The dispatch tube was relocated in the center of the desk but toward the side toward the belt, and a bell hopper was placed at the opening so that the cashier could throw the carrier in with practically no positioning. Fig. 94 shows the layout of the old and new desks.

"The new desks were made 36 in. high with a comfortable foot rest at the bottom, and a work chair with a double saddle seat and adequate back support both for working and for resting was provided. With this equipment, the cashier easily alternates standing and sitting to reduce fatigue and the work place is equally convenient for both.

"A locking device was also adopted so that the cashier no longer has to pack up her money and take it to the office every time she leaves her desk. This device has reduced the 'get-ready' time.

"Improvements were also made in the surrounding conditions. The desk lights were removed, and greater general illumination was obtained by installing larger fixtures of the proper type at regular intervals, thus providing an even distribution of light with

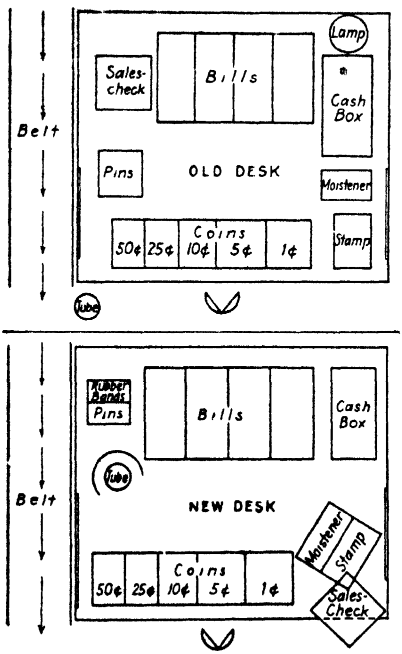


FIG. 94.—Comparison of old and new cashier's desks.

a minimum of shadows. An average uniform illumination of 18 ft.-candles was provided. Noise was lessened by covering the drums and air tubes with felt padding and the walls with acousticon. Ventilation in one tube room was improved by installing screens, and the vibrations in the tube room directly over the engine room were reduced materially by supporting the lines from the floor of the engine room instead of from the ceiling under the tube room.

"Rest pauses were also considered, and definite rest periods in the morning and afternoon were encouraged during busy periods.

Separate rest rooms were established next to each tube room, so that cashiers could relax completely without traveling a long distance to and from the regular employees' rest room.

"Other improvements were possible but were not installed because of certain limiting factors.

Setting Task and Incentives.

"Ordinarily, the next step in such a study as this would be to set the task. This is determined by the times obtained from the micromotion study, augmented by continuous-production studies made over a whole day, or representative parts of the day, to get complete information on rest pauses and delays. The task would then be set on the basis of these times and the flow of work, and an incentive plan would be developed.

"In this case, however, a standard of production and a bonus plan had been in operation for years. Since rate cutting is not consistent with the company's policy, it was decided not to change the task and the incentive plan, even though changed methods would make greater production possible with the same amount of effort.

Selection and Training of Workers.

"The establishment of the best method of doing this work made it possible for the psychological and psychiatric department to develop a definite technique for employing new persons who would make successful cashiers. Using the definite and complete analysis of the job with the degree of success of the individual cashiers as criteria, the conference office of the employment department has been able to work up standards for age and schooling and for physical, psychological, and psychiatric qualities.

"Job specifications have been worked up for interviewers which give a brief but graphic description of the job and its functions, and which also include the personnel qualifications worked up by the conference office. For the applicant, there have been prepared descriptions of the job from the employee's point of view, the nature of the job, its relation to the rest of the store, the working conditions, the task-and-bonus plan, and the promotional opportunities.

"The department of training has also found it much more satisfactory to use definite motions in training cashiers. The equipment of the tube room has been duplicated in the class-

room—the same desks, chairs, etc.—although the belt used here does not move. Real money has been substituted for theatrical money previously used in order to give definite training in handling coins and in mental arithmetic. From the first, the motions of the simo chart are used by the cashiers as the instruction card. Thus correct habits of motion are formed from the beginning.

Results of Study.

"This study of cashiers' work has benefited the customers, the store, and the employees.

"The result from the customer's point of view is that the service has been improved 26 per cent on the average. The present time required by the cashier is 17 per cent lower than the previous time of the best cashier and 40 per cent lower than the poorest of a selected group of good cashiers.

"From the point of view of the store, the study has resulted in a reduction in operating expense. Previous to the time of the study the average production of the cashiers was falling off, but since the better methods were determined, the average production has increased. The table below compares average production in 1924, before these changes were made, with that in 1926.

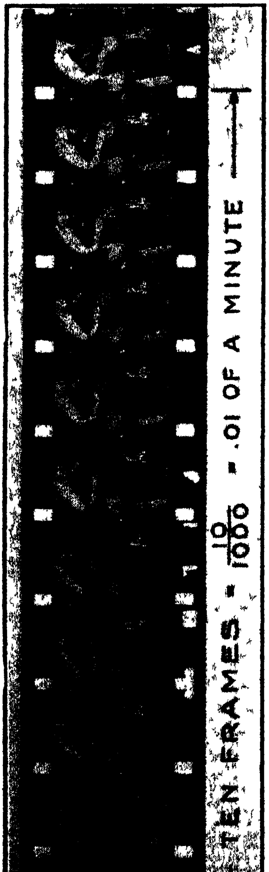
Cashiers	1924	1926	Per cent increase
Full time	543	682	25.6
Part time	362	434	19.9

"The individual production of a cashier has increased. On the busiest day in 1924, the Saturday before Christmas, before the study, the best cashier had handled 2,220 transactions. In 1925 the number had increased to 2,738.

"Another important fact which has made the tube-room operation less expensive since the study is that a shorter time is now required for the new cashiers to get up to standard production due to the improved selection and training methods.

"To the cashier herself the new method has proved advantageous also. For example, higher bonuses have been earned: During the first December after the bonus was introduced, the total bonus earnings increased 88 per cent over the December of the year before, and 44 per cent more cashiers earned a bonus,

although the number of cashiers had not increased. The cashiers are now better adapted to their jobs. Moreover, they are interested in the amount of skill they can develop and consequently find their jobs much more satisfying. And, most important, much fatigue has been eliminated, so that the cashier is able to do more work without additional fatigue. This elimination of fatigue has resulted, as described above, from eliminating waste motions and by doing the necessary motions in the best way and also by improving the surroundings and posture of the cashier."



(16 mm.-width film enlarged ½.)

FIG. 95.—Motion-picture film made with a constant-speed camera. This strip of film shows part of the "staying" operation in paper-box making.

The Use of a Constant-speed Motion-picture Camera.

A second method is that of using a constant-speed camera for making the motion pictures of the operation to be studied. The camera is an adaptation of the ordinary motion-picture camera using 16-mm. width film instead of the 35-mm. width which is used by the professional camera. This 16-mm. camera is operated by a constant-speed electric motor which is geared to the camera in such a manner that exactly 1,000 frames are exposed per minute. Since the speed of the motor will for all practical purposes be constant the time interval from one frame to the next will be exactly 1/1,000 min. Therefore the time of any element or single motion can be determined simply by counting the number of frames, or, in other words, the length of the film shows the length of time for the element or motion (see Fig. 95).

Methods of Rating.

Rating factor or leveling factor, as it is sometimes called, might be defined as the factor used to indicate the effective

speed of the operator, that is, the efficiency with which the particular operator performs his work in comparison with a definite standard, this standard being the performance of an average operator working without incentive at a preconceived, ideal, standard maintainable speed.

It is understood, of course, that the method of performing the operation is standardized before attempting to make the study.

The rating factor is applied to the base time, which is found by means of the stop watch or motion-picture camera, in order to arrive at a standard time for the job. Since there is necessarily a considerable variation in the speed or effort of different operators, it is the rating factor which makes it possible to correct for such speed variations and so determine a correct standard.

It is possible to record stop-watch readings of an operation in hundredths of a minute and, by means of motion pictures, to thousandths of a minute; therefore the base time for an operation can be determined with a considerable degree of accuracy.

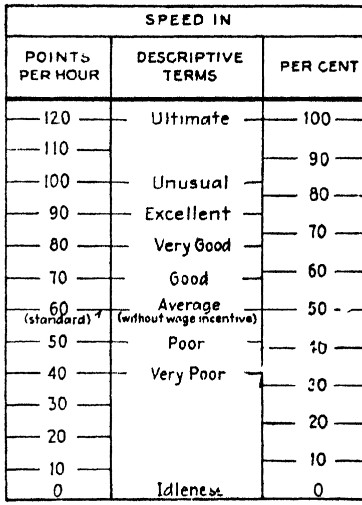


FIG. 96.—Three common systems of units used for rating speed (skill and effort) of an operator.

There are three different methods of rating in use today that are of sufficient importance to warrant our attention here. The first two are fairly well known, while the third is a recent development.

Speed and Effort Rating.

Simple speed and effort rating is the oldest and most common. The time-study observer makes the stop-watch time study in the usual manner, and during the study he rates the operator for speed and effort. That is, he compares the operator being studied with an ideal "average man" which he has in mind and uses a percentage figure (other units as shown in Fig. 96 may be used) to show the comparison of the particular operator being timed to the ideal or imaginary average. There are three sets of units commonly used for this rating figure: (1) points per hour, (2)

descriptive terms, and (3) per cent. A direct comparison of these three is shown in Fig. 96. The "descriptive-term" plan is less definite than either of the two other rating scales. This plan as well as the "percentage" plan has wide differences as to the meaning of the "average." In the percentage plan some concerns consider 100 per cent as average, while others consider 70 or 80 per cent as average with 100 per cent as the ideal.

The point plan, however, almost universally recognizes 60 as the standard or base, and it is referred to as a 60-point[1] hour. The point system requires that the time-study observer rate the operator on speed and effort at the time the time study is being made. Suppose that the time-study observer finds the operator to be working at a 70-point hour and that the nature of the work requires that a 10 per cent allowance be made for rest and delay; then 70 plus 10 per cent of 70 gives a rating factor of 77, and the base time as found by the stop-watch time study would be corrected in the following manner:

$$\text{Base time} \times \frac{\text{rating factor (with rest and delay included)}}{60}$$
$$= \text{base time} \times \frac{77}{60} = \text{base time} \times 1.28.$$

If, for example, the base time of the operation is found to be 1.00 min., then 1.00 × 1.28 gives a time standard of 1.28 min. This means that the operator will be allowed 1.28 min. per piece to perform the operation and the person who is able to do the work in less than this time will be exerting more than the standard amount of effort and therefore will do more than 60 points of work in 1 hr. In fact, if the particular operator who was time studied maintains his speed throughout the day, he will have an average point hour of 70, instead of 60 which is considered standard.

The Westinghouse Leveling Method.

A second method of rating, commonly called leveling, differs from the first method already described in that consideration is given to the rating of more than the one element, effort. Under the previously described method, the assumption is made that the tools, fixtures, methods, materials, and working conditions are standardized before a time standard is made. Since this may not be true, factors can be introduced to correct for the variation

[1] For definition of a point see p 220.

from standard. The method now used by the Westinghouse Electric and Manufacturing Company, as explained by S. M. Lowry, makes use of factors for rating (1) skill, (2) effort, (3) conditions, and (4) consistency. Table XXI is a performance rating summary[1] which gives numerical values for different degrees of each of the four factors named above.

TABLE XXI.—PERFORMANCE RATING TABLE

Skill			Effort		
+0.15 +0.13	A1 A2	Superskill	+0 13 +0 12	A1 A2	Killing
+0.11 +0.08	B1 B2	Excellent	+0.10 +0 08	B1 B2	Excellent
+0 06 +0 03	C1 C2	Good	+0.05 +0 02	C1 C2	Good
0.00	D	Average	0.00	D	Average
−0.05 −0.10	E1 E2	Fair	−0.04 −0.08	E1 E2	Fair
−0.16 −0.22	F1 F2	Poor	−0.12 −0.17	F1 F2	Poor
Conditions			**Consistency**		
+0.05	A	Ideal	+0.04	A	Perfect
+0.04	B	Excellent	+0.03	B	Excellent
+0.02	C	Good	+0.01	C	Good
0.00	D	Average	0.00	D	Average
−0.03	E	Fair	−0.02	E	Fair
−0.07	F	Poor	−0.04	F	Poor

[1] Reproduced by permission of the authors and publishers, from Stewart M. Lowry, Harold B. Maynard, and G. J. Stegemerten, "Time and Motion Study," p. 109, McGraw-Hill Book Company, Inc.

If the time-study observer finds that at the time of making a time study, the performance rating of the operator is as follows:

Excellent skill	B2	+0.08
Good effort	C1	+0.05
Average conditions	D	0.00
Good consistency	C	+0.01
Total sum to be added to	1.00	+0.14

Leveling factor = 1.00 + 0.14 = 1.14

then the base time will be multiplied by the leveling factor, which in this case is 1.14, and the product will be the standard time for the job.

Motion-picture Method of Rating.

When motion pictures are made of an operation by the use of a constant-speed motion-picture camera it is possible to project this film at exactly the same speed at which the pictures were taken and thus show on the screen an exact reproduction of the operation as often as desired. If the projector is fitted with a speed indicator to show film speed in frames per minute, and if the projector has a variable-speed motor, then it is not only possible to reproduce the exact speed of the operator, but it is also possible to run the film at slower or faster speeds and so give the effect of having "slower" and "faster" operators perform the work.

The customary method is to run the entire roll of film of the operation through the projector, selecting one cycle which contains no apparent lost time or delays. The strip of film containing this one cycle of motions is cut out of the reel and the ends spliced together to form a loop. After this is done the loop is then placed in the projector and it can be projected on the screen for an indefinite period of time.

By the two methods of rating previously explained, it was necessary for the time-study observer to do the rating at the same time that the time study was made, that is, out in the factory; and, in addition to rating the operator, it was also necessary for him to read the stop watch, record the data, and note delays, lost time, etc. With the use of the motion-picture method the observer or camera man has more time to determine the speed at which the operator is working, and, further, after the film is developed and is ready for projection, the observer

can project the film at various speeds and then, from the picture on the screen, rate the operator. This makes it possible to have 10 or 12 ratings and corresponding projector speeds appear on the data sheet as shown on Table XXII. After this information is obtained then the data can be plotted on coordinate paper as shown in Fig. 97. A straight line (curve *ABC*) can be drawn which will pass through the origin and the average position of the plotted points. The speed rating corresponding to the film speed of 1,000 frames per minute can then be located on the curve sheet (point *B*), which will give the rating of the operation for the job.

TABLE XXII.—RATING DATA

Operator, T. J. Watson, 235,789.
Observer, William K. Mason.
Dept. 23, studied June 17, 1929.
Part 435, switch lever.
Operation 12DR, drill ¼-in. hole.

Film speed, frames per minute	Speed rating, points
1,100	70
850	60
1,250	80
900	55
1,350	90
800	50
1,150	75
600	40
1,050	65
1,300	85

This average of several ratings will undoubtedly be more accurate than one estimated rating made at the time the study was taken.

Since the loop of film can be projected at various speeds, it is possible to use it to train the new time-study men and also to check the rating of all the men in the department from time to time. Most time-study men will agree that it is a very difficult task to have all members of a time-study department keep the same "mental picture" of the "average operator" in mind at all times and to rate all operations against this average operator as the measuring stick. It is here that the motion picture can be of further service in rating, for once the rating is set for the operation as recorded by the film at 1,000 frames per minute, then pictures showing operations at this speed can be thrown on

the screen at any time and for the benefit of any or all time-study observers.

The Eastman Kodak Company has carried on some very valuable research and investigations on the use of motion-picture equipment for time-study work, the motion-picture method of rating as explained above being one of their developments.

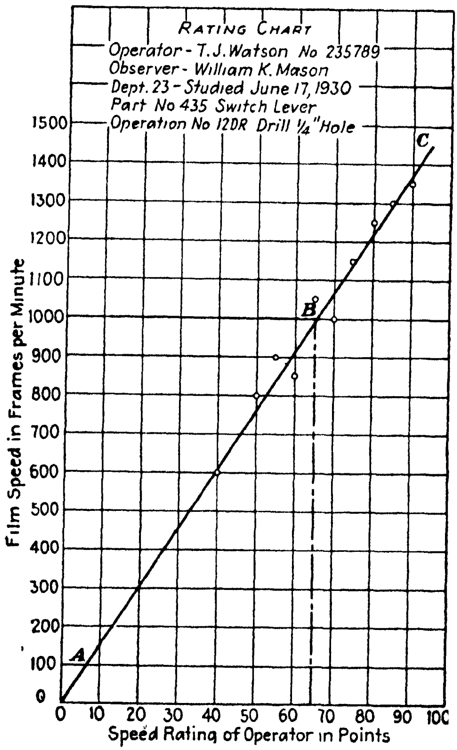


FIG. 97.—Rating chart.

This company has successfully used motion-picture methods for compiling standard time data of operations and fundamental elements so short in duration as to make stop-watch methods impossible.

Machine Delay Allowances.

It is expected that machines and equipment will be properly maintained and kept in good repair. When there is a breakdown or when repairs are necessary, the operator will be taken off

the job and of course no allowances for delays of this nature would have a place in a time standard.

There are, however, small delays or minor adjustments peculiar to the different types of machines and equipment that are too small to consider individually, yet in the course of a day or week these accumulate to an appreciable amount. Such machine delays are unforeseen and do not occur at periodic intervals and should be provided for by a machine delay allowance. This allowance is usually expressed in the form of a percentage of the base time—sometimes as a percentage of only the machine elements in the base time.[1]

There is no constant that can be safely used for machine delay allowances in all kinds of work. Some concerns run time studies for extended periods—in some cases as long as a week—in which a record is made of all delays on particular classes of machines. In this manner percentages for machine delays can be found that will approach some measure of accuracy at least. This seems to be the most satisfactory method of solving the problem, and it is far more accurate than arbitrarily setting a percentage to cover machine delays for all kinds of work in a department or a plant.

Personal Allowance.

Allowance for the personal needs of the employee is expressed in the form of a fixed percentage of the base time. This figure varies from 2 to 5 per cent, 3 per cent perhaps being the most common figure used.

Fatigue Allowance.

Fatigue is caused to a large extent by the strenuousness of the work and also by the closeness of attention required on the part of the operator. By strenuousness of the work is meant the physical effort involved. Heavy lifting, rapid hand motions where loads are involved, strained or unnatural body position while working all go to produce fatigue. Some kinds of work require little or no physical effort but may produce fatigue on the part of the worker. For example, an operator who sits all day inspecting small polished steel parts for defects in finish, cracks, scratches, discolorations, etc., is exerting very little muscular effort, but such work requires 100 per cent attention. It is evident that an allowance must be made for fatigue in this kind

[1] MERRICK, DWIGHT V., "Time Studies for Rate Setting," p. 17.

of work as in work where physical effort of a different kind is involved to a much greater degree.

The time standard should include fatigue allowances which will properly provide for the fatigue produced by the particular operation. This allowance is commonly applied as a percentage to be added to the base time.

TABLE XXIII.—JOB CLASSIFICATION[1]

Type of job			Class
Assembling	small parts		*A*
	large parts		*C*
Automatic screw machine			*A*
Burring			*B*
Boring			*C*
Drill press	medium and light work		*B*
	large work		*C*
Filing and burring	light		*B*
	heavy		*D*
Grinding: surface grinder			*B*
Lathe work	hand feed	small	*B*
		large	*C*
	semiautomatic	small	*B*
		large	*C*
Milling	hand feed		*C*
	automatic feed		*B*
Punch press	blanking		*C*
	roll feed		*B*
Snagging	small		*B*
	large		*D*
Spray lacquer			*B*
Sand blast			*C*
Shape			*B*
Tapping	small		*B*
	large		*C*

[1] Only a part of the job classification is reproduced in Table XXIII.

TABLE XXIV.—FATIGUE ALLOWANCES, PER CENT

Class of work	Cycle time, seconds					
	0 to 3	3 to 6	6 to 12	12 to 24	24 to 48	48 on
A	7	6	6	6	5	5
B	9	8	8	7	6	6
C	11	10	9	8	7	6
D	14	12	11	10	8	7

The following example shows how one manufacturing concern determines the fatigue and personal allowances to be made. The personal allowance is fixed at 4 per cent for all operations in the factory. The personal allowance is combined with the fatigue allowance in order to simplify the work needed in applying the allowances to the base time.

Procedure.—The class of work is determined by comparing the job in question with Table XXIII. The classification, having been determined, the per cent to be added to the cycle time is taken from Table XXIV.

Derivation.—The classifications of Table XXIV are based on the recognition of moderate or extreme cases of one of the following conditions, or a combination of them:

1. Strenuousness.
2. Closeness of attention necessary.
3. Unnaturalness of body position.
4. Health requirements (leaving to escape fumes).
5. Work requirements (small delays insufficient to time).

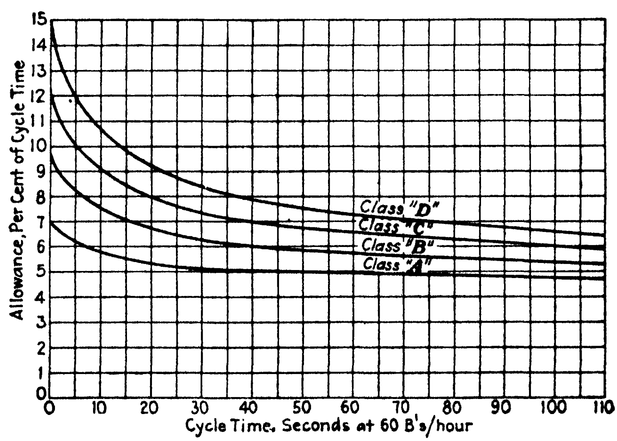


FIG. 98.—Fatigue and personal allowances.

Class A is composed of operations which do not involve any of the above conditions.

Class B operations have one of the conditions to a moderate degree.

Class C operations have one of the conditions to an extreme degree, or a combination of two or more to a moderate degree.

Class D operations have two conditions or more of extreme degree, or one, plus one or more, in moderate degree.

Table XXIV is based on the curves of the chart shown in Fig. 98 the curves for which are represented by a formula derived in accordance with the following assumptions:

a. The fatigue allowance should contain a fixed figure for personal requirements (4 per cent), which does not vary with cycle time or class of work.
b. The allowance for fatigue varies as an inverse function of the square root of the cycle time.
c. The allowance shall be 15 per cent for the shortest cycle in the hardest class and 7 per cent for the shortest cycle in the easiest class.
d. There shall be four curves for four classes of work, said curves to be so spaced that the range mentioned in *c* shall be divided equally.

In order to comply with these requirements, the formula takes the form:

$$P = \frac{K}{\sqrt{T + 0.1}} + 4$$

where

P = The allowance expressed as a percentage.
T = Cycle time in minutes.
K = 0.95 for class A.
1.79 for class B.
2.64 for class C.
3.48 for class D

CHAPTER IX

WAGES. GENERAL PRINCIPLES

There are three groups concerned in the operation of any industrial enterprise, namely, the workers who operate the machines and produce the finished product; the owners and managers who supply the capital and direct the business operations; and also the general public who consume the manufactured products.

In order to reduce the cost of production, which in turn makes possible a decrease in the selling price of the product, manufacturers in past years have studied the design of the product, approaching the problem from all angles. They have carefully selected and improved their equipment and processes of manufacture to bring about better economy; and, furthermore, they have turned to the item of direct and indirect labor with the hope of making savings there.

The manufacturer has found from experience that, in general, long working hours and low wages do not bring reduced unit labor costs. He knows that if he can persuade his employees to produce more, he can in turn pay them higher wages.

Incentives.

It is a basic human trait that increased effort is encouraged by rewarding in proportion to the effort expended. So, if the worker is paid on the basis of output, or work produced, there is a definite incentive for him to increase his effort.

The use of the time wage provides for a fixed rate to be paid to the worker. This wage is usually paid in the form of a specific hourly rate without reference to the amount of work done. However, by exercising unusual effort, or by giving sufficient thought to his job, an employee may eventually earn a promotion and a higher wage. Or, he may have his hourly rate increased even though he continues to do the same kind of work. Basically, the time wage places no emphasis on output and makes no reward for unusual effort. The incentive form of wage, on the other

hand, places no emphasis on time but provides increased earnings for increased output.

Managers have found that the incentive form of wage not only decreases their production costs but also increases the employee earnings. It is therefore evident that both the employer and the employee stand to gain by this arrangement.

Incentives may be placed on (1) quantity, (2) quality, or (3) material saved. Any one, or any combination, of these three factors may be used as a basis for an incentive form of wage payment. Ordinarily, incentives are placed on quantity of output.

Effect of Wages on Overhead Costs.

In general, it can be said that any wage-payment system that reduces the unit labor cost will also reduce the unit overhead cost. Since the employee who is working on incentive gets paid on a basis of the work which he does, it is seen that he earns more when he is producing a greater number of units per hour or per day. Therefore, the time used to perform an operation on any one piece is reduced. That means that more work can be put through the machine or process in a given time, and the overhead cost of operating this machine will be prorated over a greater number of pieces and so the unit cost will be lower.

TABLE XXV.—EFFECT OF INCREASED OUTPUT ON WORKERS' EARNINGS AND UNIT COST OF PRODUCT

Piece rate used

Number of castings machined per hour	Piece rate	Earnings of worker per hour	Material cost ($5 per 100 pieces)	Machine hour rate[1]	Total manufacturing cost	Cost per casting
15	($2 per 100 pieces)	0.30	0.75	1.50	2.55	0.17
20		0.40	1.00	1.50	2.90	0.145
25		0.50	1.25	1.50	3.25	0.130
30		0.60	1.50	1.50	3.60	0.120
35		0.70	1.75	1.50	3.95	0.113
40		0.80	2.00	1.50	4.30	0.108
45		0.90	2.25	1.50	4.65	0.103
50		1.00	2.50	1.50	5.00	0.100
55		1.10	2.75	1.50	5.35	0.095

[1] Overhead chargeable against the machine. This includes power, light, heat, floor-space charge, depreciation of machine, taxes, repairs, insurance, etc.

The data in Table XXV show how the total unit cost decreases with the increased output under the piece-rate system of wage payment. The marked reduction in unit cost with the increasing output is brought about because of the relatively high machine hour rate in this particular case.

Increase in the Use of Wage Incentives.

There has been a steady increase in the use of incentive forms of wage payment in this country during the past 25 years, and at the present time perhaps half of all workers in the manufacturing industries are paid under this system.

The National Industrial Conference Board recently made a survey of 1,214 plants employing 777,376 workers, representing a little more than 9 per cent of all wage earners in manufacturing industries in this country. The following table shows the distribution of workers by systems of wage payment:

TABLE XXVI.—DISTRIBUTION OF WORKERS BY SYSTEMS OF WAGE PAYMENT, 1928[1]

System of wage payment	Number	Per cent
Time wages	367,454	47.2
Straight piece rates	218,321	28.2
Other piece rates	69,265	8.9
Special incentive systems	122,336	15.7
Total	777,376	100.0

[1] National Industrial Conference Board.

From the above table it is seen that 47.2 per cent of the workers were paid by time wages while 52.8 per cent were paid by some incentive form of wage payment. It is of interest to know the relation that the size of the industrial plant has to the type of wage system used. This is shown by the table on page 184.

In 1928 the National Metal Trades Association made a survey of the systems[1] of wage payment used in the 672 plants in their association. They found that 307, or 45.7 per cent, of the plants paid all employees on a straight time basis, while 365, or 54.3 per cent, paid some or all employees on an incentive basis. In

[1] "Methods of Wage Payment," National Metal Trades Association, Committee on Industrial Relations, W. E. Odom, director.

TABLE XXVII.—DISTRIBUTION OF EMPLOYEES IN PLANTS BY SIZE OF ESTABLISHMENT AND SYSTEMS OF WAGE PAYMENT, 1928[1]

Number of employees	Number of employees in plant				
	Total	Using time wages	Using piece rate and other incentives		
			Piece rates	Piece rates in combination with other incentives	Other incentive systems without piece rates
1 to 150	37,173	16,627	16,463	1,792	2,291
151 to 350	76,277	17,061	43,094	8,373	7,749
351 to 750	96,932	16,444	51,938	18,074	10,476
751 to 1,500	128,068	5,305	73,660	30,477	18,626
151 to 1,500	301,277	38,810	168,692	56,924	36,851
1,501 to 3,500	128,337	4,595	87,173	25,511	11,058
3,501 and over	310,589	4,829	141,420	126,788	37,552
1,501 and over	438,926	9,424	228,593	152,299	48,610
Total	777,376	64,861	413,748	211,015	87,752
Percentage distribution					
1 to 150	100.00	44.73	44.29	4.82	6.16
151 to 350	100.00	22.37	56.49	10.98	10.16
351 to 750	100.00	16.96	53.58	18.65	10.81
751 to 1,500	100.00	4.14	57.52	23.80	14.54
151 to 1,500	100.00	12.88	55.99	18.90	12.23
1,501 to 3,500	100.00	3.58	67.92	19.80	8.62
3,501 and over	100.00	1.56	45.53	40.82	12.09
1,501 and over	100.00	2.15	52.08	34.70	11.07
Total	100.00	8.34	53.22	27.15	11.29

[1] "Systems of Wage Payment," National Industrial Conference Board, 1930, p. 7.

the 365 shops using incentive plans covered by this survey, 489 incentive plans of wage payment are in use as follows:

247 or 50.5 per cent, piece work.
104 or 21.3 per cent, premium.
53 or 10.8 per cent, bonus.
33 or 6.7 per cent, group plans.
52 or 10.6 per cent, miscellaneous.

In 1927, the Sherman Corporation made a survey of over 1,100 companies employing over 500,000 workers, and they found 49 per cent of the companies using incentive plans. This survey revealed the fact that 65 per cent of the plants manufacturing automotive products used the incentive form of wage payment.

Major Requirements of a Good Incentive Wage Plan.

There are certain essentials that incentive wage payment plans should have to insure their successful operation. It is impossible to make a complete list of requirements and expect them to fit all cases fully. In general, the following principles are essential:

1. Guaranteed minimum wage.
2. Proper incentive.
3. Standards set by time study.
4. Standards guaranteed against change.
5. A system easy to understand and simple for the employee to figure earnings.
6. A system that will facilitate time keeping and pay-roll computation.

Guaranteed Minimum Wage.

Under the time wage system the worker knows in advance what his earnings for the week or pay period will be. If he is paid, for example, 60 cts. per hour and he works 44 hr. per week, he is certain to receive $26.40 in his pay envelope. Under the straight piece-rate plan he receives a variable amount of wages depending upon the work that he does during the week. In order to protect him against very small weekly wages that might result because of low output for the week and possibly through no fault of his, it is desirable to guarantee a minimum wage to the worker. Then if his piece-rate earnings go above this guaranteed wage

he is paid on the piece-rate basis. Since the guaranteed wage is somewhat lower than the average piece-rate earnings, it is evident that the worker will seldom permit his output to fall to the low level.

There is a certain assurance that the guaranteed minimum wage gives to the worker that is very desirable and this point should be given consideration in any wage system.

Proper Incentive.

The promise of increased earnings is not the only incentive that may be offered to a workman to persuade him to increase his output. The assurance of steady work, or the granting of extra vacation or holidays, while not identical with increased earnings, indirectly has this idea in the background. There are non-financial incentives that are in some cases very powerful. In a well-known machine-tool plant, definite time standards have been set on all work, and the workers' efficiency is calculated daily on the basis of work done, against the time standards. The efficiencies are posted on a bulletin board located in a conspicuous place in the department. No direct financial rewards are made, since the workers are paid a flat hourly wage, yet there is a very noticeable incentive present. This is particularly true among the better workers, who compete among themselves to keep their efficiency rating near the top of the list.

While some managers have tried to capitalize on so-called non-financial incentives, it is not safe to place too much reliance upon them. It is a much better plan to offer a definite monetary incentive and assure the worker in this way that he is getting in his pay envelope each week the wages that he has earned.

Straight piece rate offers increased earnings to the worker in direct proportion to output, while a 33⅓ per cent Halsey plan, on the other hand, gives the worker only one-third of the earned output above the standard. Taylor made the following statement with regard to amount of incentive:

"The writer has found, for example, after making many mistakes above and below the proper mark, that to get the maximum output for ordinary shop work requiring neither especial brains, very close application skill, nor extra-hard work, such, for instance, as the more ordinary kinds of routine machine shop work, it is necessary to pay about 30 per cent more than the average. For ordinary day labor requiring little brains or

special skill but calling for strength, severe bodily exertion, and fatigue, it is necessary to pay from 50 to 60 per cent above the average. For work requiring especial skill or brains, coupled with close application, but without severe bodily exertion, such as the more difficult and delicate machinist's work, from 70 to 80 per cent beyond the average; and for work requiring skill, brains, close application, strength, and severe bodily exertion, such, for instance as that involved in operating a well-run steam hammer doing miscellaneous work, from 80 to 100 per cent beyond the average."[1]

There is considerable difference of opinion as to the proper incentive that should be paid to a worker on a given job. This is evident if one examines the many different wage-payment systems now in use. Some managers think that there should be no sudden break in wages at any point in performance such as the Gantt, the Merrick, and the Taylor differential piece-rate plans use. Where abrupt changes in earnings are present, there is danger of misunderstandings on the part of the workers when they fail to receive the higher rate at the break point.

Many manufacturers use the equivalent of a straight piece rate with carefully determined time standards as the basis for the incentive plan This gives an absolutely fair incentive to the employee and at the same time it insures against overpaying which might occur if the rates were set up in a haphazard manner.

Standards Set by Time Study.

When an incentive form of wage payment is used there must be some standard on which to base the incentive. Some task must be set as the standard day's work, and then a reward may be given to the worker for accomplishing the task. Even in the straight piece-rate plan some standard is needed in determining the rates.

Standards are set from past records, from estimates made by the foremen or supervisor, from timing pace setters, or from time studies made of the workers themselves. The first three methods named are, in general, unreliable and inaccurate for setting direct labor time standards. In order to be highly satisfactory, wage incentives should be based on standards which have been set up by time-study methods. This, alone, insures a fair wage to the worker and a fair return in work done

[1] TAYLOR, F. W., "Shop Management," p. 26.

to the employer. It removes the temptation for the employer to "cut" rates and does away with "easy" and "hard" jobs for the worker. Fair and uniform tasks are necessary in gaining the confidence of the employees. It is important that standardization of tools, materials, and methods be complete before time studies are made on the job.

The task may be expressed either in the form of time (hours or minutes) or in the form of money (dollars or cents). For example, the standard time for drilling a ½-in. hole in a bar of steel might be set as 2.00 min. per piece. Or, if a piece rate is used on this job and it is expected that the operator will earn $0.60 per hour, then the standard piece rate would be set as $0.02 per piece or $2.00 per hundred pieces. In the first case the standard is expressed in the form of time, and in the second case in the form of dollars. Piece rates are widely used and form a very simple method of calculating the pay roll, yet there is a considerable amount to be said in favor of using a time standard as the base. When it is desired to change the wage level, it becomes necessary either to raise or to lower the piece rate when that form of wage payment is used or to change the base rate if time standards are used. A factory may have 20 or 30 different base rates in use, while a similar plant using piece rates would have thousands of different rates in force. The time standards remain fixed and unchangeable as long as the operation is performed in the manner in which the operation was timed. This means that base rates are entirely independent and separate from time standards and that base rates may be changed without affecting time standards.

Standards Guaranteed against Change.

Once a time standard has been set, it should not be changed unless there is an important change in the method, tools, equipment, or conditions on the job. When a change in the time standard becomes necessary, the new standard should permit the worker to earn as much as he earned under the old standard and at no increased expenditure of effort.

Such a guarantee to the worker makes the incentive real and insures that the worker will do his best to turn out a large day's work without the fear that the time standard or the piece rate will be changed because he has earned "too much."

The National Metal Trades Association asked its members to report[1] the circumstances under which their rates or standards might be changed. The 243 companies reporting gave 567 reasons for changes. The frequency of mention is as follows:

317, or 55.9 per cent, only in case of change in method, process, tool, or design.
94, or 16.5 per cent, in case of flagrant error in establishing rates.
56, or 9.8 per cent, revised upward only.
36, or 6.3 per cent, with changes in general labor market.
24, or 4.2 per cent, only at end of year.
22, or 3.8 per cent, only by mutual agreement with employee.
11, or 1.9 per cent, on evidence of undue fatigue.
4, or 0.7 per cent, "when necessary."
3, or 0.5 per cent, when starting new crew.

A System Easy to Understand and Simple for the Employee to Figure Earnings.

It seems that it might be taken for granted that the system of wage payment should be simple enough for the worker to understand, yet there are some plans of wage payment so complicated that even a well-educated person would find it difficult to calculate his earnings. Every worker prefers to know what he earns each day. Many employees keep a record of the amount of work which they do and calculate their earnings and check the pay-roll department. The wage system should make this possible. This requires that the time standards or piece rates be clearly stated and that the method of wage payment be carefully explained to each employee. Piece rate is the simplest to understand of all the incentive plans, for it is necessary only for the worker to multiply the number of pieces by the rate in order to determine his earnings for the day. Any wage system that does not permit the worker to calculate his earnings for the day operates under a handicap.

Since some of the workers do not care to check their output per day, it is desirable to post efficiency or output sheets in each department each morning, listing each worker's production for the previous day. The form on page 225 shows a very satisfactory way in which to handle this matter. There is a psychological advantage in having the output sheet posted each day.

[1] "Methods of Wage Payment," p. 15, National Metal Trades Association, Committee on Industrial Relations.

Above all, it is necessary that the employee feel certain that his wages are accurately determined and that the whole matter is being handled in an open and fair manner.

A System That Will Facilitate Time Keeping and Pay-roll Computation.

A very important point in favor of the use of group incentive forms of wage payment is that they simplify the pay-roll calculations. Any wage system that requires elaborate and minute time-card reports, intricate bonus or efficiency calculations, and complicated methods of cost distribution is certain to have a high administrative cost.

It is entirely possibly that a system of wage payment might require considerable clerical work, such as the Bedaux system demands, and yet justify such expense because of the control features that are present in the system. This point is fully explained in another chapter.

Group Incentive.

Group incentive may be defined as an incentive applied to a group of employees working on related operations and affecting the combined output of these workers collectively. When the incentive relates to the performance of a separate individual it is called an individual incentive.

The extended use of the production and assembly lines, and the increasing interdependence of operations in industry within recent years, has led many manufacturers to adopt the group incentive in place of the individual incentive. It is claimed for the group incentive that it:

1. Develops a spirit of cooperation and teamwork among the members of the group and reduces labor turnover.

2. Induces the skilled workers to help the beginners and slower employees.

3. Saves in clerical work and pay-roll calculations. The worker does not need to use job tickets, and the clerical work of checking elapsed time of operations is eliminated. It is not necessary to make an individual "count," and time records are not necessary on separate operations.

4. Reduces work in process. This is true because the group is paid only for the work that passes an "inspection point."

5. Promotes alertness on the part of the members of the group. The workers look for operations that are behind and help in every way possible to get the maximum production through the group. In many cases the workers virtually plan their work and supervise themselves.

6. Reduces scrap and defective workmanship.

7. Simplifies factory cost determination.

R. F. Whisler, of the National Cash Register Company, makes the following statements with regard to the uses and limitations of the group incentive.

1. "Where a number of people complete a part or job by a series of operations and in a progressive manner, generally with the aid of conveyors, group incentives are best. In some instances they are necessary. Assembly lines are good examples of this class of work.

2. "Where machines are operated on a multiple basis (more than one machine per operator) and there are several operators, group incentives are applicable. Automatic screw machines and power mills are examples of this class.

3. "Where work is performed by a number of people working collectively and the individual's output is not readily obtainable, group incentives are necessary. Labor gangs, material handlers, groups operating plating machines, woodworking machines, and stokers are examples.

4. "Where each operator completes his operation without aid of others and the work passes on to the other departments, individual piece work is best. Punch presses, drill presses, subassembly departments are examples.

5. "In general, we believe that the individual incentive is productive of more consistent results and satisfies a man's desire to 'work for himself' with the result that the workmen are better satisfied."[1]

The above statements are of further interest when it is known that the National Cash Register Company has in active production over 44,600 different parts which involve 500,000 detailed operations. Some models of the cash registers have nearly 12,000 parts. The company had for nearly 40 years used piece work as the main method of paying for direct labor. In 1924 a group bonus system of incentive was tried out; after 3

[1] Whisler, R. F., Uses and Limitations of Group Incentives, *Factory and Ind. Management*, vol. 78, No. 1, p. 43, July, 1929.

years this system was modified, and at the present time the group incentive takes the form of group piece rate.

An Application of Group Incentive.

H. G. Perkins, industrial engineer for the Chrysler Motor Corporation, states that it has been the policy of his company for many years to use extra incentive methods of wage payment.

"The individual piece-work method was first selected and placed in operation throughout our shops. The routine set up for securing a measure of the output of each employee was considered adequate at the time of installation, but a thorough investigation made some time later revealed the disturbing facts that piece-work counts were very inaccurate, that instances of fraudulent practices were too numerous to be ignored, and that the expense involved in checkers, shop clerks, and office employees was excessive. It was evident that changes and improvements were necessary. The management desired a method that would produce the greatest quantity of quality product at reasonable cost, with a minimum of scrap and expense, and with an attractive return to the workman.

"An exhaustive analysis of various methods was made and the practices of other concerns were studied, with the result that a decision was made to install a group method of payment to our so-called productive workers.

"This method provides that workmen be grouped in logical units having a community interest, each member of the group receiving a guaranteed hourly rate regardless of the production secured and a bonus based on the relation between the actual production of the group and the standard performance. As a means of securing an accurate and fair measure of the relation between the standard and actual production, an amount of time is allowed for doing each unit of work. This time, which is set by the Time Study Department, is known as the standard time and represents the amount of time required by average good workmen to do the job consistently over an extended period of time. The actual time consumed by a group in doing a job is compared with the standard time to determine a per cent of efficiency, and this efficiency is the basis for the amount of bonus paid. The greater the production the higher become the efficiency rating and the amount of bonus.

"Observance of certain fundamental principles was recognized as being essential to success, and these have been religiously observed.

"These principles are:

"1. Individuals can be grouped successfully only when they have a community interest in the result of their combined efforts.

"2. Individual interest in individual accomplishment must be retained, the success of the group being based on individual incentive and ambition.

"3. The group must receive all the directly increased wages accruing from increased production.

"4. The plan used must be sufficiently simple to be understood by the workmen.

"5. There must be confidence in the management, induced by the square deal.

"6. The supervisory and operating personnel must believe in the group idea.

"7. The system should be installed by thoroughly competent specialists, who are familiar with the functions of the time, cost, inspection, planning, and shop departments.

"8. There must be a just distribution of group earnings to the individuals of the group.

"The last named of these principles requires routine that is sufficiently flexible to operate successfully when recognition is given to the following variables:

"1. Different degrees of skill and ability are required on different operations within the group.

"2. Different degrees of skill and ability will be found in different employees engaged on the same or parallel operations within the group.

"3. Veteran employees are entitled to more consideration than are newcomers."[1]

Presenting Group Bonus to the Employees.

The following material is taken from a pamphlet written primarily for the employees. It explains clearly one of the very common forms of group bonus application:

[1] PERKINS, H. G., "Extra Incentive Wage Plan for Groups in the Chrysler Motor Corporation." A.M.A. Production Executives Ser., No. 16.

GROUP BONUS PLAN

Nov. 10, 1927.

"Our company is adopting a group bonus plan of wage payment, and we want our employees to help us and give us their sincere cooperation.

"Wherever it is possible, we wish to give our employees the opportunity of working under the group bonus plan.

"Employees are formed into groups, each group having specific duties to perform.

"Your earnings will increase in proportion to the efficiency of the group of which you are a member.

"You will be guaranteed your base rate wherever group bonus is applied.

"Wherever practicable, day work will be performed in the group and will be considered 100 per cent efficiency or your base rate plus 20 per cent bonus.

"A standard time in which an operation should be performed is set for each operation—based on actual time study—and will represent 100 per cent efficiency. By referring to the bonus table, you will observe that 100 per cent efficiency pays 20 per cent bonus on your base rate.

"At the end of each day, checkers will forward to the office group credit memorandums covering all of the parts that have passed a given point.

"Quantities credited to the group are multiplied by standard time, to get total standard hours credited.

"A record of actual time applied to each group by various employees is taken by timekeeper.

"Efficiency is obtained by total actual hours divided into total standard hours.

"*Example.*

Standard hours credited	=	400
Group actual hours worked	=	350
400 ÷ 350	=	114.2 per cent.

"Referring to bonus Table XXVIII, 114.2 per cent efficiency allows 36.8 per cent bonus.

Workman's base rate	=	40 cts.
Actual hours worked	=	105
Therefore, 105 hr. × 40 cts. base rate	=	$42.00
36.8 per cent bonus ($42.00 × 36.8 per cent)	=	15.46
Total base earnings plus bonus	=	$57.46
Earnings per hour on this basis	=	55 cts.

TABLE XXVIII.—BONUS TABLE

Per cent		Per cent		Per cent	
Efficiency	Bonus	Efficiency	Bonus	Efficiency	Bonus
75	1.0	117	40.4	159	90.8
76	1.6	118	41.6	160	92.0
77	2.2	119	42.8	161	93.2
78	2.8	120	44.0	162	94.4
79	3.4	121	45.2	163	95.6
80	4.0	122	46.4	164	96.8
81	4.6	123	47.6	165	98.0
82	5.2	124	48.8	166	99.2
83	5.8	125	50.0	167	100.4
84	6.4	126	51.2	168	101.6
85	7.0	127	52.4	169	102.8
86	7.6	128	53.6	170	104.0
87	8.2	129	54.8	171	105.2
88	8.8	130	56 0	172	106.4
89	9.4	131	57.2	173	107.6
90	10.0	132	58.4	174	108.8
91	11.0	133	59.6	175	110.0
92	12.0	134	60.8	176	111.2
93	13.0	135	62.0	177	112.4
94	14.0	136	63 2	178	113.6
95	15.0	137	64.4	179	114.8
96	16.0	138	65.6	180	116.0
97	17.0	139	66.8	181	117.2
98	18.0	140	68.0	182	118.4
99	19.0	141	69.2	183	119.6
100	20.0	142	70.4	184	120.8
101	21.2	143	71.6	185	122.0
102	22.4	144	72.8	186	123.2
103	23.6	145	74.0	187	124.4
104	24.8	146	75.2	188	125.6
105	26.0	147	76.4	189	126.8
106	27.2	148	77.6	190	128.0
107	28.4	149	78.8	191	129.2
108	29.6	150	80.0	192	130.4
109	30.8	151	81.2	193	131.6
110	32.0	152	82.4	194	132.8
111	33.2	153	83.6	195	134.0
112	34.4	154	84.8	196	135.2
113	35.6	155	86.0	197	136.4
114	36.8	156	87.2	198	137.6
115	38.0	157	88.4	199	138.8
116	39.2	158	89.6	200	140.0

No bonus is paid for group efficiency below 75 per cent. Bonus of 1.2 per cent is added for each 1 per cent of efficiency above this table. For example, 201 per cent efficiency pays 141.2 per cent bonus; 202 per cent efficiency pays 142.4 per cent bonus; and so on up. All groups expected to show efficiency of at least 100 per cent.

"Bonus of 1 per cent is paid at 75 per cent efficiency and graduates according to efficiency attained by the group:

100 per cent efficiency will pay 20 per cent bonus.
105 per cent efficiency will pay 26 per cent bonus.
110 per cent efficiency will pay 32 per cent bonus.
120 per cent efficiency will pay 44 per cent bonus, and so forth.

"All groups are expected to show an efficiency of at least 100 per cent.

"Average efficiency shown at the end of a pay period will be credited to the group.

"The point to keep in mind at all times is that actual hours should be less than standard hours. The fewer actual hours and the more standard hours a group shows at the end of a pay period the bigger the amount of bonus earned.

"The company wants each group to make as high a percentage of bonus as possible, without any fear of a reduction.

"Credits will be allowed only for good production. But when parts are defective for any cause of the company, such as defective material, error on forms, etc., full credit for operations performed will be allowed. Cost for repairing defects caused by group will be deducted from the group.

"If a group finds that it can get along just as well with fewer members, the members that are not needed can be transferred and the remaining members will be able to make larger bonus."[1]

Results of the Group Bonus Installation.

The plan of group bonus as explained above was installed in 1927 and has been in effect since that time. The following statements indicate the results obtained from the use of this plan:[2]

"1. Our experience has shown that the group wage-payment plan is extremely satisfactory for many jobs, but it cannot by any means be applied 100 per cent throughout the factory to all jobs.

"2. In so far as we can estimate at present, our employees have been able on the average, to increase their earnings approximately 10 per cent, whereas the company has received approxi-

[1] From "Mueller Group Bonus Plan," a pamphlet issued to their employees by the Mueller Company.

[2] Statements are quoted from a personal letter to the author from one of the officials of the company, dated Dec. 19, 1930.

mately 25 to 27 per cent increase in output. These figures, of necessity, are merely approximate, but in checking them in different manners they seem usually to check fairly close.

"3. We have found that there seems to be no limit, within reason, of course, to the number of people that can be in a group so long as the material passing through that group is worked on by many of the individuals of the group and comes out of the group as an identified article.

"4. Our factories are now operating on the new standard cost system, with which the group plan works in extremely well. Also, of necessity, it becomes an important part of the standard costs.

"5. We have found in a group bonus plan that the clerical work attached to it in counting of the output, in crediting the standard hours, in figuring the bonuses, and in taking care of our costs is tremendously less than it would be on a piece-work plan or on an individual bonus plan, and, therefore, we prefer to use the group plan wherever it is at all possible.

"6. We found after a short time that the method of group bonus operating in our foundries was not so satisfactory as we had anticipated. In some instances we changed the group bonus to a plan of individual bonus, and it immediately settled our difficulties."

Incentive on Quality.

Although most incentives are placed on production, it is possible to place the incentive in a manner that will give any results that may be desired. If quality is a very important factor in the manufacturing process, and if the alertness and concentration of the operator directly affect the quality of the product, it is then very often profitable to place an incentive on quality, or perhaps on a combination of both quality and quantity of the product.

Robert F. Miller, industrial engineer for Stevenson, Harrison and Jordan, explains the use of a premium system for maintaining high production at low cost and at the same time protecting the quality of the product. This combined incentive plan was worked out for the welding department of a chain manufacturing concern, and its operation is as follows:

"The operation of welding chain is a machine job on which the operator runs from one to six machines. The chain (pre-

viously formed into links in the preceding operation) is run through the welding machine and each link is butt welded by electrical heat. The quality of the chain is measured by the number of bad links, detected by inspection. The inspection consists of (1) a tensile test in which the chain is subjected to a pull of a definite load and (2) a hand inspection of each link to detect cracked links developed by the tensile test, welding blemishes, and other defects. When a portion of chain is perfect except for a slight blemish, its marred appearance disqualifies it as first-class chain. It is then called "binder chain" and is coupled up and used as second-class chain.

"From this it is clear that the measure of the quality of the welded chain is (1) the number of bad or scrap links detected and (2) the amount of second-class chain found. Incidentally, the inspectors are paid a premium for the number of bad links detected.

"The first step in the establishment of the quality bonus was the setting of accurate piece rates on each size and type of chain welded. These rates were expressed in cents per 100 lb. of finished chain and were based on time study and an analysis of past production figures. After these piece rates had been in effect several months, a record was made of the amount of scrap links and binder to determine the actual quality on each kind and size of chain. With this as a starting point, a standard range of quality was set up on every type of chain. This range of quality gave the spread between the standard and the allowed quality. For instance, on one type of chain the quality range set was 0.92 to 2.77 bad links per 1,000 lb. of chain welded. Standard quality in this instance is 0.92 bad links per 1,000 lb. or less, allowed quality is less than 2.77 and more than 0.92. The measure of quality is obtained by dividing the number of bad links by the pounds welded. For example, if there were 4 bad links on 5,000 lb. of chain, the quality was 0.80 bad link per 1,000 lb.

"The basis of payment under the quality bonus plan is as follows: The welder is paid for the chain he welds at the piece-rate price. As the report comes through to the office from the inspection department showing the number of pounds inspected and the bad links found (if any), the actual quality is computed as explained above. If, as in the example cited, the actual quality is better than the standard, a premium of 10 per cent

of the piece-rate price is paid for every pound of chain inspected. Suppose in this example that the piece-rate price is \$0.76 per 100 lb. The premium earned would be

$$\frac{5,000}{100} \times 0.76 \times 10 \text{ per cent} = \$3.80.$$

If the number of bad links were 10 instead of 4, the actual quality would be 2.00 (in other words, more than the standard of 0.92 but less than the allowed figure of 2.77). No premium would be paid, the welder would simply be paid the piece-work price. If, on the other hand, the number of bad links were 20, the actual quality would be 4.00, or greater than the allowed figure of 2.77. In this instance a penalty would be imposed of 10 per cent of the piece-rate price of \$3.80. In brief, then, the plan pays a 10 per cent premium for bettering standard quality, imposes a 10 per cent penalty for less than allowed quality, and pays nothing extra for quality in the allowed range.

" . . . it was found that the improvement in quality over past averages was remarkable. On some types of chain, where the quality was almost entirely controlled by the welder, the number of bad links was reduced to as much as one-thirtieth of what it had been. Even on automatic welding, where the operator runs from two to six machines and consequently does not have so close control over quality as the operator running one machine, there has been a substantial increase in quality, ranging from 10 to 60 per cent. The average improvement was 54 per cent, which, after taking into account the premiums paid, showed a net saving to the company of more than \$10,000 a year."[1]

Incentive on Material Saved.

In the leather-cutting department of a well-known manufacturing concern, seven men cut \$500,000 worth of leather in a year, and the pay roll of these seven men is around \$11,000 for the year. Since various shapes are cut from a side of leather, it requires considerable care on the part of the cutter to get the maximum amount of usable leather from a side. With the cost of the material amounting to about fifty times the pay roll, it certainly would not be desirable to overemphasize the output factor and underemphasize the material-saving feature. In

[1] MILLER, ROBERT F., Paying Quality Premiums, *Factory and Ind. Management*, vol. 78, No. 6, p. 1346, December, 1929.

fact, a strong incentive to save material would bring about greater economy in this department.

An Example of Incentive Based on Output, Quality, and Material Saved.

The Holeproof Hosiery Company uses an incentive based on three factors, namely, output, quality, and saving of material. This company tries to balance the incentive on each of these three phases in such a way that they get just the results desired.

The following example[1] will indicate how these three factors affect the earnings of the inspector:

"I. *Quantity of Hosiery Inspected.*

"Quantity is paid for on the basis of a standard time unit which has been set by time study. The computations are as follows:

Number of dozen inspected × standard time unit × base rate = earnings for quantity of production.

"II. *Quality of Perfects Passed.*

"Defective hosiery is separated from perfect in accordance with definitely prescribed quality standards given in a manual of inspection rules.

"The accuracy of this separation of imperfects from perfects is of prime importance and is measured by a system of spot reinspection. This reinspection gives the percentage of errors made by the inspectors. As the accuracy of the inspection is dependent upon the degree of familiarity with the inspection rules and the degree of concentration of the operator in his search for defective spots, it is appropriate to induce this condition in the operator by an incentive based on the results. Computations of reward or penalty on this factor are made by comparing actual percentage of defects with the allowed percentage of error according to the following formula:

Actual per cent defects − standard per cent error × 10 × pay earned on factor I = reward or penalty.

"This result may be either gain or loss. It is added algebraically with earnings on the other two factors. Attention is

[1] BRINKMAN, E. E., Let Incentives Talk in Dollars, *Factory and Ind. Management*, vol. 78, No. 5, p. 1066, November, 1929.

directed to the use of a multiplying factor of 10, to make the formula correspond in pay results with the variations in quality of work. This multiplying factor makes the incentive on this phase of their work as powerful as the quantity incentive in factor I.

"III. *Waste of Material.*

"While this inspecting operation is of such a nature that no raw material is consumed in its operation, there is still present the possibility of the operator's rejecting too many perfects in her zeal to achieve a high-quality classification. The waste resulting from this practice is as serious as the avoidable spoilage of good yarn in the knitting process. In order to balance this phase of the job with phases I and II, an incentive is provided. Spot reinspection measures and controls this. Computation of pay earned on this factor is the same as for factor II.

"Summarizing these three factors and applying them to a representative case, the pay for an inspector would be computed as follows:

Factor I. 1,200 dozen × standard time unit of 0.05 hr. × base rate of 60 cts. per hour = \$36.00.

Factor II. (Actual of 1.8 per cent defects − standard of 1.5 per cent) × 10 × \$36.00 = \$1.08.

Factor III. (Actual waste of 1.1 per cent − standard of 1.5 per cent) × 10 × \$36.00 = \$1.44.

Adding these factors algebraically (\$36.00 − \$1.08 + \$1.44) gives \$36.36 as the total pay."

Incentives Applied to Indirect Labor.

There are several approaches that may be used in applying incentives to indirect labor. The method explained in the next two chapters is commonly employed. However, the following plan is more definite and accurate, and perhaps more satisfactory, for some types of work.

Trucking, like most kinds of materials handling in the factory, is classed as indirect labor; and it is generally accepted that it is more difficult to set standards on indirect than on direct labor. The following case will explain the method used by one manufacturer, and the curves in Fig. 99 show the result of the use of incentive over a period of years.

The application of incentives was made on electric-lift trucks used in the plants of the Norton Company.

"In short, the problem—as we saw it, at least—was to find some simple plan of keeping all our truckmen on the job all the time. . . . We started with a single lift truck and had certain departments call up when a platform was ready to be moved. A time-study man rode with the driver for several days, and from his studies it was found that the driver averaged 30 moves a 9-hr. day. So we decided to make 40 trips the starting point of the bonus plan. For 40 trips or less a day, the day rate was paid. Then a graduated bonus scale was set up. For trips over 40 and up to 45, the operator received a bonus of 5 cts. a trip for all

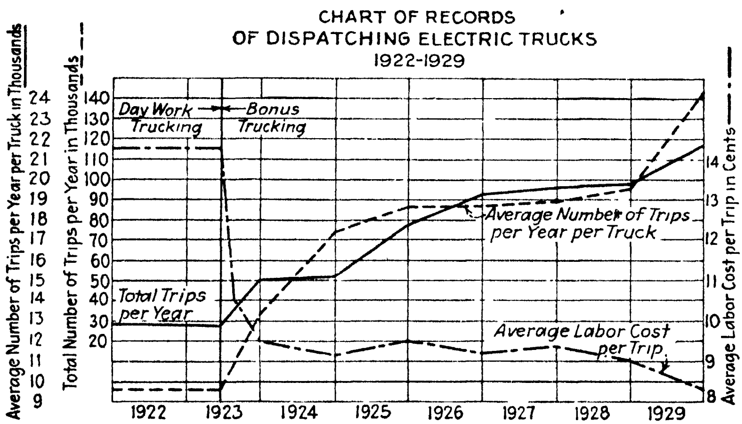


FIG. 99.—Curves showing the effect of wage incentives, and a central truck-dispatching plan on labor costs.

trips over 40, in addition to his day rate; from 45 to 50, the bonus was 6 cts.; and so on. This scheme was explained to the truckers—there were three at the time—and they were told that there was only enough work for two and that those two would be expected to handle the work previously done by three operators.

"The very first day the two men were able to handle the work in 9 hr. Operator 1 made 62 trips for which he was paid the day rate of $4.50 plus a bonus of $1.98, making a total of $6.48. The other operator made 56 trips and earned a bonus of $1.28. In short, they did about double the work formerly handled on day work, and their earnings increased about 35 per cent. We saved 35 per cent in labor and laid up one truck which cost $9.00 a day.

Now there are five truckers on bonus, handling from 300 to 350 orders a day."[1]

Maintenance Incentives.

"Except, however, for a few companies where incentive work is older and more generally used, interest in maintenance incentives is of relatively recent origin. There are several reasons for this:

"1. It is usually more difficult to measure and establish accurate standards for maintenance work, making the initial or installation cost higher.

"2. There is a prevailing attitude in many organizations that incentives are not applicable to maintenance work.

"3. In only the larger companies do we find large enough maintenance groups so that the various crafts are organized into separate departments, making possible departmental applications of only related work.

"4. Even after the work is measured and standards are established, the application of the standards presents clerical problems not ordinarily found in production work, due to the greater difficulty of accurately checking daily performance.

"5. Because of the varied nature of maintenance work, cost systems are apt to treat maintenance costs rather generally and are, therefore, not so likely to reflect accurately the effect of incentive applications in terms of dollars-and-cents savings. Certainly, management pays more attention to the control of direct labor costs than to indirect labor costs.

"This last reason is one of the strongest arguments for maintenance incentives, because there is a natural tendency to adjust the productive labor force almost immediately with changes in volume of production, whereas there is much less likelihood that maintenance crews will be adjusted so promptly, if at all. In any event, there is almost sure to be a lag.

" . . . We selected for the first application a small group of five men who were engaged in repairing and reconditioning used valves. Some of the variables which we encountered were as follows: Sizes varied from ¼ in. to 12 in.; designs represented every important valve manufacturer; there were screw ends and flanged ends; materials included brass, cast iron, monel, or

[1] HILDEBRANT, B. A., The Right Handling Equipment, *Factory and Ind. Management*, vol. 79, No. 6, p. 1345, June, 1930.

combinations of different metals; types included globe valves, angle valves, gate valves, check valves, gas cocks, etc.; the completed valve had to test tightly for different pressures according to the type of service in which it was used, as soap, acids, alkalis, glycerin, water, gas, steam, air, and all kinds of oils; the used valves were received in all conditions of damaged or broken parts and of corrosion and rust.

"Time studies showed the necessity for standardization of methods and procedure. It was necessary to plan work more advantageously and to establish somewhat better control of the inventory of repair parts and material. A complete classification

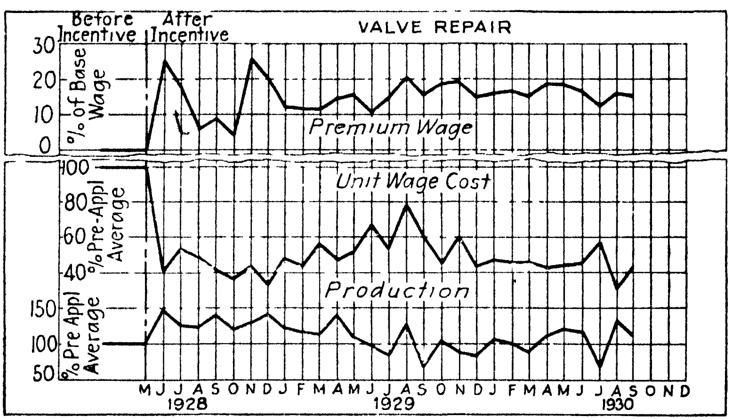


FIG. 100.—Curves showing the effect of wage incentives on earnings, unit labor cost, and production, for maintenance work.

was made first as to type of valve, then as to operations on each type. Sufficient time studies were made on a number of different sizes of each type to insure that the resulting operation standards were representative of average conditions. Knowing the number of used valves started in any lot, a few inspections during the day and an inventory of completed work turned into the storeroom at the end of the day provided a satisfactory check on the day's performance. This application has now been in effect 2½ years.

"Figure 100 shows graphically the results of this application. I have gone into considerable detail because it was our first one on maintenance work, and it was the example which convinced us of the possibilities.

"The next thing we tackled was scrubbing and cleaning our railroad tank cars, of which our company owns in the neighborhood of 1,500. Except when a car is to be loaded with the same material which it last contained or a lower grade of similar material, it must be thoroughly cleaned on the inside before reloading. A regular crew of 10 men, including a straw boss, average 13 cars a day on day work. A regular crew of 4 men, including a working straw boss, now do 12 cars a day, or 6 men will do 18 cars a day . . .

"We favor individual incentives where applicable but use the group plan where the work is of a cooperative nature and where clerical work would be excessive to determine individual performance.

"The next two applications of maintenance incentives were to the plant painters (between 10 and 15 men) and to the railroad-car repair shop (around 30 men). These incentives have now been in operation for 2 years. The painting pay roll has not been greatly reduced, but the amount of painting has increased nearly 75 per cent, partly due to more frequent painting and partly to new painting work or the taking over of painting work formerly done by production departments.

In the car-repair shop are made practically all kinds of repairs to railroad tank and box cars, including boiler-making operations such as fabricating, bending and fitting plates, drilling, scarfing, calking, riveting, and blacksmith work . . .

"In all, we have about 75 maintenance men on standards. Unit wage costs are showing a steady reduction. Premiums paid to operators average about 14 per cent over base wage. Cost of making and maintaining these applications has been about $29,000, against which substantial savings have been realized."[1]

Specific Recommendations.

The Manufacturers' Research Association appointed a committee in 1926 to "analyze and compare the present-day methods of paying wages for the purpose of discovering and segregating those features which are inherent in all effective systems." The principles of wage payment advocated by this committee include the three general types of payment:

[1] Lowry, Stewart M., Maintenance Incentives, *Factory and Ind. Management*, vol. 80, No. 6, p. 1156, December, 1930.

I. *Piece Work*.—A general term for payment of the individual on the basis of amount of work produced.

A. Standardized shop methods prior to time study.

B. Production rates set only on the basis of accurate time study.

C. In order to make it possible to measure and compare the efficiency of operators and departments, the establishment of a definite task becomes at once desirable. For a good, average worker the attainment of this task would represent 100 per cent efficiency.

D. Guarantee a day work rate for operators in all cases where the worker is unable to perform this task, on account of conditions beyond his control. It would charge these excess costs to the proper expense account and distribute them together with other overhead charges.

E. Establish definite breaking-in periods for new operators.

F. Provide instruction cards prescribing the exact conditions under which all operators should work, *i.e.*, feeds, speeds, number of pieces per hour, set-up time, etc. In addition to these instruction cards, there would also be rate cards showing base rates and the amount of production an operator must turn out in order to obtain these rates.

G. Advocate paying a flat reward to any operator who presented an improved method for performing a task, after which it would recommend that a new rate be established for performing the task in accordance with the new method.

H. Provide and maintain accurate records of production and scrap. Whenever it is possible to do so, it would pay a bonus for minimum scrap.

I. Provide that a weekly analysis sheet be made up from the reports turned in. This would permit executives to obtain direct control of labor costs.

J. Under this plan of wage payment, the tasks of all indirect workers are studied and the proper ratio of direct to indirect labor established for each department.

K. If so desired, a bonus may be paid to indirect workers based on the ratio of the direct to the indirect labor hours in any given department, established in the manner described in the preceding paragraph. The exact method of computing this bonus, and the time interval between any two payments thereof, should be determined by the management of any company in such a way as to satisfy the needs and requirements of the particular business.

II. *Group Piece Work*.—It is expected that this plan would be used when it would lend itself to the work in hand.

III. *Day Work*.

A. Where the cost of establishing standards exceeds the savings which may be reasonably expected to result from the substitution of unit rates of production for day wages, a day wage is recommended.

B. Wherever, after careful study, it seems feasible to supersede day work by piece work, this step is recommended.

The plan as recommended by the committee eliminates the following objectionable features inherent in some other systems;

1. Decreasing rates per piece for added increments in production above standard.
2. Sharing the workers' savings with management.
3. Difficulty on the part of the worker of understanding the plan and computing his earnings.
4. Time-studying operations where shop conditions have not previously been standardized.[1]

National Metal Trades Association's Recommendations.

The following report was made after a study of the plans of wage payment used by the 672 plants covered in the survey. The committee stated in presenting the recommendations that "it would seem that the following eight broad rules and principles should be observed in the adoption and administration of an incentive plan:

"1. The work in question should be studied in detail and definite methods of operation adopted. The process of determining the best way to perform the operation may be called methods engineering, time study, motion study, job standardization, or motion-time analysis; but whatever means is used, the best way to do the job should be carefully and completely determined before anything else is attempted.

"2. Rates or standards should be established only as a result of a series of accurate studies and should be subject to such checks and rechecks before definite adoption as to make unnecessary any later change in the rate or standard as long as the job itself remains unchanged.

"3. A definite task, bogey, or other measure of what constitutes a day's or a week's work should be established so that the performance of individuals, groups, or departments may be readily measured and compared.

"4. Employees should be protected against the possibility of reduced earning power due to circumstances beyond their control. This refers to the inefficiency of management as exemplified in an interruption of the flow of materials, a shortage of proper tools or equipment, the breakdown of machinery, or an inadequate power supply. This is generally accomplished by the use of a guaranteed minimum time wage or hourly rate.

[1] Rich, A. B., Principles of Wage Payment, *Bull.* Taylor Soc., vol. 11, No. 4, p. 214, October, 1926.

"5. The wage incentive used should be sufficiently flexible to permit application to the maximum number of jobs and the maximum number of employees.

"6. The wage-payment plan for indirect labor and supervision should be such as to harmonize with the incentive plan used for direct labor, so that there will be no conflicting interests between the different groups of employees. For instance, the pay of inspectors should not be based upon the number of defective pieces found, as a feeling of mistrust between the respective groups of employees involved will be engendered, whether justified or not. Neither should departmental foremen be paid an incentive to keep the indirect-labor ratio down when it may be possible that an increase in indirect labor might be more than offset by a consequent increase in total departmental production.

"7. Whatever plan of wage payment be used, it is most important that the plan itself be simple enough to be readily understood by all employees. The employee should not only be able to compute his earnings independently of the pay-roll department but should be able readily to relate such earnings to his individual productive effort. The most patient efforts are necessary to insure that all employees fully grasp the methods by which their pay is computed, for if they do not fully understand, there is a fertile field for gossip and misunderstanding.

"8. Under all circumstances and under all conditions the plan or plans of wage payment should not only be fair and just to employee and management alike but should scrupulously avoid any appearance or even suggestion of unfairness in any sense whatsoever.

Your committee therefore:

"1. Urges members to use an incentive plan of wage payment whenever and wherever possible.

"2. Recommends that the foregoing eight rules and principles be closely adhered to.

"3. Points out the superiority of the simple types of incentive plans, such as ordinary piece work with guaranteed day rate, over the more complex systems.

"4. Emphasizes the fact that a spirit of mutual confidence and faith based on square dealing between employees and management is essential to maximum satisfaction from all standpoints."[1]

[1] Methods of Wage Payment, p. 18, by permission of the National Metal Trades Association, Committee on Industrial Relations, W. E. Odom, director.

Plans Which Are Justified, for What, Why, and How.

With the many systems of wage payment in use today is it any wonder that surveys, such as the two referred to above, are instigated by manufacturers in order to find out for themselves which plans are justified?

C. W. Lytle has carefully analyzed 25 of the common systems of wage payment, and from these he selects 10 which he thinks would supply all the needs. These 10 plans[1] are:

"1. *Day rate plan* with production records and promotion. For unstandardized work, permanent, or temporary. It is simple and about all that can be used. Management should eliminate it wherever and whenever possible.

"2. *Multiple time plan* with high bonus steps. For upgrading employees formerly on day rates. It is one of the strongest as well as simplest of plans. It must be more carefully managed than a more elaborate plan.

"3. *High piece-rate plan* with or without a minimum guarantee and with the time basis of computation. For repetition work not involving expensive machine rates. It is the simplest and the soundest of all the plans. Equalization requires care, as task per unit of time may not be evident.

"4. *Merrick multiple piece-rate plan.* For upgrading inefficient employees formerly on low piece rate. It is flexible, strong, and relatively simple for what it can do. Tables must be used for explanation and computation.

"5. *Gantt task and bonus plan* (a combination of items 1 and 3). For machine jobs liable to delay and where machine rates are high. It provides security with strength. The day guarantee may need watching.

"6. *Halsey* (50–50) *constant sharing plan.* For guessed-at standards, no big machine rates. It gives a high wage through intermediate production efficiencies. Task or rate inaccuracy is less serious.

"7. *Bedaux point plan.* For strongly centralized management and for widely diversified operations. It gets results through its production control rather than through high rates. It involves a lot of figuring.

"8. *Barth variable sharing plan,* up to day wages only. For beginners. It gives a high wage for low production efficiencies

[1] LYTLE, C. W., "Wage Incentive Methods," p. 59, The Ronald Press Company, by permission of the author and publisher.

without guarantee. Tables must be used, the new employee may not have a slide rule.

"9. *Emerson empiric scale plan,* between 70 and 100 per cent task only. For gradual transition from day work plan to high piece-rate plan. It avoids the abrupt step and may be justified in some cases. The empiric principle is used only within the above limits; outside these, other plans are preferable.

"10. *Bigelow-Knoeppel constant sharing plan,* up to 70 per cent high task. For beginners. It makes a simple and just plan for these limits with less earning than under day wage and more than under piece rate. It is probably easier to understand than the Barth plan for the same purpose. It is not recommended beyond 70 per cent task."

Mr. Lytle further states:

"As to the other 15 plans, none of them has inherent merit not to be found in the above, except perhaps the 15 class gradation of Parkhurst. If the scale of efficiency bonus seems important, that may be made up for any of the above plans. Job standardization, production control, inspection, and non-financial incentives must precede and accompany any plan to get anything worthwhile out of it. Similarly, any one plan may be applied to a group or put on a minute basis. We may be wrong, but with malice toward none, we sincerely believe that these 10 plans provide us with every kind of incentive which we need today and which we are likely to need for a long time to come. Various combinations of these plans are desirable, but they should not be given new names other than perhaps plant names indicating where used."

CHAPTER X

WAGES. BASE-RATE DETERMINATION

The cost of labor is one of several factors which enters into the selling price of a product, and very frequently the manufacturer is likely to consider the payment for labor in much the same way as the purchase of steel, coal, lumber, or any other raw material. However, there is a difference between the two. To the worker his wages are of vital importance, his well-being and in most cases his very livelihood are dependent upon his weekly earnings. A fair wage properly administered is satisfactory to the worker and to the manufacturer alike. If the purchasing department makes a mistake and buys inferior material, it can be scrapped or perhaps returned to the vendor, but if the laborer is not properly selected for the task and fairly compensated for the work which he does, not only will the manufacturer fail to get the work done the way he wants it, and at a proper unit cost, but the worker will not be fairly provided for.

Need for Uniformity in Base Rates.

It is fundamentally essential that industry provide a satisfactory wage to labor. There are many economic theories[1] as to just what constitutes a satisfactory wage, but space does not permit us to go into them here. It will be admitted that regardless of whether the share going to labor in the form of wages under our present industrial system is correct or not, a very great step forward will be taken when we establish some uniformity in wages within a given industry or within a given industrial area.

It is not at all uncommon to find a wide variation in the base wages of men doing identical work in different departments of

[1] WATKINS, G. S., "Introduction to the Study of Labor Problems," Chap. VI.

the same shop. In a machine-tool plant, for example, men operating radial drills in one department were receiving 56 cts. per hour, and in another department other workmen doing similar work on identical machines were paid 68 cts. per hour. It is entirely too common an evil to find this lack of uniformity in base rates within a plant as well as among factories in the same vicinity.

Where labor is paid by the hour, the base rate is guaranteed irrespective of output. Where the workmen are paid on a piece-rate basis, the rates should be standardized in such a manner that every workman receives a satisfactory wage with no "easy" or "hard" jobs in the plant. The rates are usually set up on assumed hourly earnings below which the average worker is not expected to fall, and in many concerns this base rate is guaranteed to the worker even where an incentive form of wage payment is used. It is evident that whatever the form of wage payment used, the base rate is the foundation upon which premiums, bonuses, or additional incentives are based, regardless of the nature of this additional wage. The base rate plus any added incentive wage then equals the total wage or earnings of the worker.

Using this conception of the term base rate, it is evident that for any type of wage system that may be used, base rates must first be established for each worker, or for the job or occupation.

Base Rate for the Individual Worker.

Since workmen vary in ability, skill, education, and many other personal qualifications, it seems logical that an employee might be paid a wage based upon his personal qualifications. Each employee being hired to do a particular job would have his base rate determined to a certain extent by the nature of the work, but also such factors as length of service with the company, loyalty and enthusiasm, number of dependents in his family, etc., might influence the base rate in cases where rates are set for the individual worker rather than for the job or occupation.

Base Rate for the Job or Occupation.

Some manufacturers think that the fairest and most satisfactory base rates are set for the occuptaion rather than for the

individual. Thus, if a specific operation on a radial drill is worth 65 cts. per hour to one man operating the machine, this same wage should be paid to any and every man operating the machine provided he is competent to do the work. In order to make sure that a new employee is suited to the job for which he is hired, it is customary to have a beginning rate, somewhat lower than the standard rate for the job. This beginning rate should terminate at the end of a definite period. The Frigidaire Corporation of Dayton, Ohio, has made satisfactory use of three base rates for each occupation in its factories. A beginner's rate of, say, 50 cts. per hour would be paid for 1 month, the qualifying rate of 53 cts. per hour for a period of 6 months, after which time the standard rate of 58 cts. per hour would be paid.

Where base rates are set for the occupation, the only way in which the employee can increase his base rate is by becoming qualified to perform work requiring greater skill and better training and consequently having a higher base rate. It is important at this point to note that we are discussing base rates and not incentives. Of course, a bonus or premium on output would make it possible for the employee to increase his earnings on any job for which an incentive was in force.

Determination of the Worth of an Occupation.

In order to determine accurately the worth of an occupation it is necessary to analyze it very carefully, especially when we come to consider the wide variety of jobs found in any good-sized industry. For example:

"At the Kodak Park Works of the Eastman Kodak Company, 4,800 employees in chemical and mechanical processes which produce continuous products are used on 902 different jobs or grades of jobs, and in addition to this there are 1,100 to 1,200 employees in the engineering and maintenance shops representing 18 different trades and working on over 200 different operations."[1]

Merrill R. Lott, gives the following factors[2] which he says determine the worth of an occupation:

[1] PALMER, VIRGIL M., Determination of Base Rates for Manual Workers, *Amer. Management Assoc. Bull.* 36.

[2] LOTT, MERRILL R., Wage Scales With a Reason, *Management and Administration*, vol. 9, No. 5, p. 451.

	Factors	Weight
1.	Time usually required to become highly skilled in an occupation	23
2.	Time usually required for a skilled person in the occupation to become adapted to employer's needs	7
3.	Number of men employed in an occupation in the locality, the labor supply	5
4.	Possibility of an employee's locating with another company, with a similar earning capacity	4
5.	Educational requirements of an occupation	10
6.	Prevailing rate of pay in locality	5
7.	Degree of skill, manual dexterity, accuracy required	9
8.	Necessity of constantly facing new problems, variety of work	9
9.	Money value of parts worked on, possibility of loss to company through personal errors (unintentional)	6
10.	Dependence that must be placed upon the integrity and honesty of effort of employee	7
11.	Cleanliness of working conditions	3
12.	Exposure to health hazards	3
13.	Exposure to accident hazards	3
14.	Physical effort required	3
15.	Monotony of work	3
	Total weight of points	100

The above table suggests a means of analysis for jobs of all kinds. Once the analysis is made, the elements of the job can be compared with other jobs or occupations in the factory. This offers a means of comparing the value of one kind of work with that of another, and some approach to a scientific method can be used in setting a just and fair base rate on the many different jobs in the factory.

A careful study was made of the method of base-rate determination used by one large manufacturing concern, and since this plan seems to be typical of that used by other firms it will be given in detail.

N. D. Hubbell has worked out and successfully applied the following method for setting base rates, to an industry employing over 7,000 workers:

Occupational studies are made, time studies taken, and after careful analysis, the base rate is then set for the work. Instead of 15 factors as listed above, only 7 are considered by this company. The point system of wage payment, which gives a premium to the worker for increased output above 100 per cent efficiency, is used in this plant. The base rate is equal to the average of wages paid for similar work in the community.

TABLE XXIX.—FACTORS USED IN THE DETERMINATION OF THE INDEX FOR THE JOB

Factor	Weight, points
1. Dependability	25
2. Time required to learn job	20
3. Job knowledge	15
4. Job skill	10
5. Educational requirements	10
6. Adjustability	10
7. Working conditions	10

TABLE XXX.—DEPENDABILITY

10. General foreman.
9. Foreman.
8. Assistant foremen.
7. Working gang leader.
6. Minor supervision, directing a helper.
5. Exacting work, occasional supervision.
4. Ordinary work, occasional supervision.
3. Ordinary work, ordinary supervision.
2. Close work, close supervision.
1. Rough work, close supervision.

TABLE XXXI.—TIME REQUIRED TO LEARN JOB

10. 5 years or over.
9. 3 to 5 years.
8. 2 to 3 years.
7. 1 to 3 years.
6. 6 to 12 months.
5. 3 to 6 months.
4. 1 to 3 months.
3. 1 to 4 weeks.
2. 1 to 6 days.
1. Less than 1 day.

TABLE XXXII.—JOB KNOWLEDGE

10. Complicated technical knowledge and calculations.
9. Simple technical knowledge and calculations.
8. Considerable technical knowledge and judgment.
7. Elaborate practical knowledge and judgment.
6. Ordinary practical knowledge and judgment.
5. Covered by technical standard practice.
4. Covered by complicated practical standard practice.
3. Covered by simple standard practice.
2. Simple directions, varied.
1. Simple directions, routine.

Table XXXIII.—Job Skill

10. Varied delicate trade skill.
9. Varied trade skill, high degree of accuracy.
8. Varied trade skill, ordinary grade.
7. Delicate operation and adjustment.
6. Varied trade skill, rough work.
5. Varied ordinary skills, handy-man type.
4. Ordinary skill, varied operations and adjustment.
3. Ordinary skill, repetitive operations and adjustment.
2. Highly repetitive, rough skill.
1. Labor type, no skill required.

Table XXXIV.—Educational Requirements

10. High school, special courses and experience.
9. Eighth grade, regular apprenticeship and experience.
8. Eighth grade, technical information and experience.
7. High school or regular apprenticeship.
6. Eighth grade and trade knowledge.
5. Eighth grade.
4. Sixth grade and trade knowledge.
3. Sixth grade.
2. Read, write, and simple calculations.
1. Speak and understand English.

Table XXXV.—Adjustability

10. Several special jobs simultaneously.
9. Several routine jobs simultaneously.
8. Quick changes, special jobs.
7. Special jobs, covered by standard practice.
6. Quick changes, routine jobs.
5. Variety of routine jobs.
4. Routine, similar jobs.
3. Complicated repetitive job.
2. Helper type of jobs.
1. Repetitive job, short cycle.

Table XXXVI.—Working Conditions

Add two points for each disagreeable feature:

a. Machine hazard.
b. Acids.
c. Fumes.
d. Slippery floor.
e. Heavy lifting.
f. Odors.
g. Wet.
h. Heat.
i. Dust.
j. Grease.
k. Eye strain.

Name of job:

Name of employee studied: Reg. No.

How long studied: Studied by:

Bldg. No. Dept. Date

I. General description of job.
  1. Regular duties. List all regular duties and show degree of Supervision required. Use scale 1 highest to 5 lowest. Use back of sheet if necessary to give complete description (see instruction manual for classifications under each type).
  2. Irregular duties. List and show degree as above. In addition show approximate time spent on each.
  3. Hours of work (check one which applies)
     Regular day Irregular day Night
     Trick without Sunday Trick with Sunday
     Vacation privileges

II. Specifications for employees.
  1. General requirements.
     a. Sex: Male Female
     b. Is it advisable to employ only Americans on this job?
     c. Age most desirable Age limits
     d. Length of training required (check one which applies)
        (1) Unskilled (laborers, few days to train)
        (2) Semiskilled (few weeks to train)
        (3) Skilled (6 to 12 months to train)
        (4) Highly skilled (over 1 year to train)
  2. Educational requirements.
     a. Check degree of education recommended.
        (1) None (4) High school year
        (2) Read and write English (5) College or technical
        (3) Grammar school grade (6) Special courses
     b. What educational factors actually enter into job?
  3. Job intelligence. Knowledge and information regarding job.
     How long required to learn.
     By whom taught.
  4. Manipulative skills. What hand skills must be acquired.
     How long required to become proficient.
     By whom taught.
  5. Tools, reference books, etc.
     a. List tools or instruments used on the job which require special training.
     b. List reference books, charts, tables, etc., used.
  6. Accuracy. Degree and kind required.
  7. Working conditions: Inside Outside
     Give lighting conditions.
     List any disagreeable or hazardous features such as noise, dust, odors, fumes, acids, grease, floor or machine hazards, etc., and any special clothing or protection needed.
  8. List jobs to which promotion is most probable and show if this job gives definite training for them.
  9. Could this job be handled by an employee who is hampered by old age or infirmity.
  10. General nature of work (use percentages when divided).

Bench.	Floor.	Machine.	
Variety.	Repetitive.	Routine.	
Slow movement.	Medium.	Fast.	
Paced by machine.	By other persons.	Self.	
Standing.	Sitting.	Walking.	
Pushing.	Lifting.	Climbing.	
Light.	Average.	Heavy.	Laborious.
Strain bodily.	Mental.	Eye.	Nervous.
Strain none.		Slight.	Severe.
Eyesight required: Normal		Exceptional	

  11. Personal qualities (use scale of 1 highest to 5 lowest).

Adjustability.	Dependability.
Resourcefulness.	Directing ability.
Initiative.	Appearance and manner.
Cooperation.	Decision.
Neatness in work.	

  12. Aptitudes (use scale 1 highest to 5 lowest).

Manual dexterity.	Comprehension.
Ambidexterity.	Ingenuity.
Eye-hand coordinations.	Memory.
Ear-hand coordinations.	Sustained attention.
Mechanical ability.	Mental alertness.

  13. Point out any additional qualifications not covered specifically in the above.

FIG. 101.—Occupation study sheet.

An analysis of the job is made when time studies are taken. This gives the time-study observer an opportunity to give careful thought to the work involved. The occupational study sheet shown in Fig. 101 is filled out by the time-study observer and then turned over to the person in the factory who has charge of setting all base rates. This person checks the occupational study sheet, makes additional observations of the job himself, perhaps has a conference with the worker on the job, the supervisor, or the foreman, and, after finding all about the job, then determines the index number for the job using the tables shown on pages 215 and 216.

Suppose that the job to be analyzed is that of a band-saw operator.

From Table XXX the band-saw operator would be given the index of 4 (ordinary work, occasional supervision), then:

Factor		Weight for final index number
1.	Dependability = 25 × 4 = Table XXX, index 4 (ordinary work, occasional supervision)	100
2.	Time required to learn job = 20 × 4 = Table XXXI, index 4 (1 to 3 months)	80
3.	Job knowledge = 15 × 2 = Table XXXII, index 2 (simple direction, varied)	30
4.	Job skill = 10 × 3 = Table XXXIII, index 3 (ordinary skill, repetitive operations and adjustments)	30
5.	Educational requirements = 10 × 3 = Table XXXIV, index 3 (sixth grade)	30
6.	Adjustability = 10 × 3 = Table XXXV, index 3 (complicated repetitive job)	30
7.	Working conditions = 10 × 6 = Table XXXVI, machine hazard, dust, eye strain	60
	Total....................................	360

The sum of the seven factors gives a total of 360, which is the index number for the job. Now referring to the curve in Fig. 102, it is possible quickly to find the base rate for the job whose index is 360. This base rate is 56 cts. per hour, and consequently this base rate would be set for this job and guaranteed to the operator who does this particular kind of work on the band saw. So, for all other jobs having a total index of 360,

the base rate would be set at 56 cts. per hour, for they would be equally difficult to perform.

The Determination of the Hourly Base-rate Curve.

It is apparent that the total index number will be of little value without the hourly base-rate curve as shown in Fig. 102. This curve was determined in the following manner: A number of jobs (which are very common in all shops) were selected as typical, and these were then rated as described above, in order to find the proper index. These jobs were analyzed not only by the person designated to set the base rates but also by the

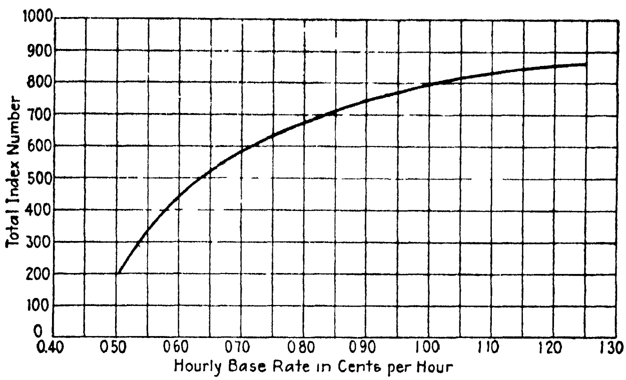


FIG. 102.—Curve for setting base rate from occupational index number.

foremen, superintendents, supervisors, and in some cases even the men themselves. An average was then taken of these, and the true index was obtained. Then the base rate that was being paid, one that seemed fair and equal to the community standard wage for similar work, was used, and the curve was then plotted from these data. The data below are typical of those obtained and used for plotting the original hourly base-rate curve, as shown in Fig. 102.

Occupation	Total index number	Hourly base rate
Janitor	200	0.50
Sensitive drill operator	335	0 55
Tool maker	635	0.75
Foreman	845	1.15

CHAPTER XI

THE POINT PLAN. A SYSTEM OF WAGE PAYMENT AND LABOR CONTROL

METHOD OF OPERATION

The point system is more than an incentive plan of wage payment in that it forms a means of analyzing and controlling in a practical manner the cost, efficiency, and compensation of direct and indirect labor in the factory and office.

The Bedaux "point" plan and the Haynes "manit" system are among the most commonly known wage-payment plans that use a uniform time unit, or point, for measuring work. Bedaux has coined the term "*B*" and Haynes the word "manit" to be used as the common denominator for all labor performance in factories using their systems.

Point plans of wage payment are widely used in industry today, although they vary considerably in the manner of installation and in their plan of operation. The following is an explanation of one of the very highly developed point plans which has been successfully applied in the factories of a manufacturing concern employing approximately 15,000 workers.

Definition of the Point.

The point is the unit of measure of human effort, consisting of a certain amount of useful work plus time allowances for rest and delays, the total of all equaling one minute. The amount of useful work in a point is based upon the performance of an average operator working without incentive at a preconceived ideal standard maintainable speed at which he will produce 60 points per hour. It is understood that the relative amount of work, rest, and delay in a point will vary with the nature of the work. That is, for work requiring heavy physical exertion a greater allowance will be made for rest than for work requiring little effort. The total will in all cases, however, equal 1 min. of time at a 60-point hour. It is expected that a properly trained

and experienced worker will be able to produce around 80 points per hour on work for which he is fitted.

Point Standard.

A point standard is the number of points allowed for the performance of a given amount of work. This standard is set by time study, and the worker is guaranteed that the standard will not be changed unless there is a change in the method of performing the operation.

Since there is a point standard set for each operation in the factory, the operator knows at the end of the day how efficient he has been. The term productive point hour is used to indicate the efficiency of a direct operator and is the average number of points produced per hour.

For example, assume that a girl is working on a small drill press and that she finishes 200 pieces in an 8-hr. day, being allowed two rest periods of 8 min. each. Suppose the point standard for drilling the casting is three points per piece, then the point hour for this operator is:

$$\text{Point hour} = \frac{(\text{good pieces finished} \times \text{point standard}) + \text{allowances}}{\text{number of hours worked}}$$

$$= \frac{(200 \times 3) + (2 \times 8)}{8}$$

$$= \frac{616}{8} = 77.$$

This means that the operator has done 77 min. work per hour or worked at a 77 point hour.

Incentive.

Since the operator is producing above the standard of 60 points per hour, she is given a premium based upon the premium points that she has produced during the day. The premium points are the points produced in excess of 60 per hour. In the above case the premium points per hour are (77 − 60) 17. For an 8-hr. day the premium points are (616 − 480) 136. The premium earned by the operator is based on three-quarters of the premium points. If the base rate of the operator is 35 cts. per hour, then her premium is $^{136}/_{60} \times \frac{3}{4} \times 0.35 = \$0.595$ (use 0.60). The base earnings for 8 hr. at 35 cts. per hour is $2.80. The total earnings for the day is then the base earnings

plus the premium, or \$2.80 + \$0.60 = \$3.40. Since the operator is guaranteed a day rate, the minimum wage in the above case, that the operator can earn for the day is \$2.80, and of course the amount earned above this minimum of \$2.80 will depend directly upon the output of the operator herself.

Production at 60.

If the operator is performing work for which point standards have not been set, or for which present standards do not apply, then the work is turned in at 60 points per hour (equivalent to day work) regardless of the amount of work done. This is called "production at 60."

Allowances.

Allowances are delays in production beyond the control of direct labor. In some cases the department is held responsible, while in other cases the cause is beyond the control of the department. In either event, the direct labor is not held responsible. All delays are reported in minutes on the daily premium card. The time allowed is added to the points produced during the day, as illustrated above in the case where 16 min. were added for the rest periods.

Delays are also divided into two classes (see Figs. 105 and 106) as follows:

1. Lost-time, department responsible, as:
   a. Machine holdups.
   b. Waiting for work.
   c. Material trouble.
2. Lost-time, department not responsible, as:
   a. Rest periods.
   b. Early quit (women employees).
   c. Fire drill.
   d. Lunch ("shift" work).

Time Study.

Stop-watch time study is usually the most convenient and satisfactory method of setting point standards. The methods employed are similar to those used by most industrial concerns with the exception that considerable attention is given to rating the operator being timed. It was stated previously in the definition of a point that it was based on the amount of work

done in 1 min. by an average operator working without incentive and that this rate would be called a 60-point hour. It is evident that in timing new operations it will be almost impossible to find an operator working at just a 60-point hour. It, therefore, becomes necessary for the time-study observer to have the standard 60-point hour speed well fixed in his mind in order that he may be able to rate other operators using this average operator as his measuring stick.

If a drilling operation, for example, is to be timed and the time-study observer rates the particular operator at a 65-point hour, he is indicating that this operator is working faster than the standard and that in order to set uniform point standards it is necessary to use this factor to get the standard back to the 60-point hour basis. The exact method for doing this is explained in Chap. VIII.

Departmental Checker.

A checker is maintained in each department or building to see that the operators are turning in their work on the proper operation number, that the count is correct, that the new work is turned in on "production at 60" until point standards can be set up, etc. Also, the checker makes out the daily premium cards. The checker is directly under the superintendent in charge of the point system and is not responsible to the production foreman in the department.

Daily Premium Card.

Figure 103 shows a common type of daily premium card which is made out by the checker in the department. He enters the information in columns 1, 2, 3, 4, 5, 6 (the inspection department in some cases necessarily fills in column 6). The cards are sent to the pay-roll department at the end of the day and they fill in all other information and calculate the premium and total earnings for the operator.

The premium card summarizes all of the work done by the operator in one day. John M. Simms did three jobs during the day of July 23, as the premium card shows (Fig. 103). The first job, "form switch arm," has a standard time of 1.3 points per piece. Simms did 125 pieces in 2½ hr. The points earned for this job are 162, or (125 × 1.3 = 162). For the day the

points earned on all three jobs are 615. The time actually worked is $8\frac{3}{4}$ hr. The operator's point hour is:

$$\frac{615}{8\frac{3}{4} \times 60} \times 60 = 70.25 \text{ (use 70)}.$$

The operator's base rate is 60 cts. per hour in this case. He works $8\frac{3}{4}$ hr., so his base earnings for the day is $60 \times 8\frac{3}{4} =$ \$5.25.

Premium is:

Points made = 615.

Minutes worked = 525.

Premium points = 615 − 525 = 90.

Premium = $\frac{90}{60} \times 0.60 \times \frac{3}{4} =$ \$0.68 (equivalent to the 75 per cent Halsey plan).

Total earnings for day:

5.25 + 0.68 = \$5.93.

REG NO AND NAME 93274 John M Simms DATE July 23, 1928

START	FINISH	HRS	OPER NO	DESCRIPTION	QUANTITY	STD	POINTS	BASE	P
7 45	10 15	$2\frac{1}{2}$	2432-A	Form Switch Arm	125	1 3	162		
10 15	3 00	$3\frac{3}{4}$	136-D	Drill Lever Body	90	2 9	261		
3 00	5 30	$2\frac{1}{2}$	1246 R	Drill "D" Lever	35	5 5	192		
1	2	3	4	5	6	7	8		

Total Hrs	$8\frac{3}{4}$	Base Amt	5 25	Checked by
Total Points	615	Premium	68	
Point Hour	70	Total Earnings	5 93	Approved by

FIG. 103.—Daily premium and time card. A card like this is made out daily for each productive operator. A green card is used by nonproductive labor.

Premium Posting Sheet.

A premium posting sheet giving the operator's point hour, his premium earned, and the total number of points produced for the previous day is posted in the department for the benefit of the direct labor working there. Figure 104 shows how the posting sheet appears; and the arrangement is such that the operator can tell at a glance just what he earned the previous day,

and if there are any misunderstandings they can be settled at once. There is also a very valuable psychological advantage to posting the efficiencies (point hours) of all of the workmen in a department, as it stimulates a spirit of competition among them.

Indirect Labor.

It is possible, in most cases, to place nonproductive or indirect labor on a standard in such a manner that such time will be prorated according to the productive work done in the department and they will participate in the premium. The foreman, for instance, will receive a premium based upon the supervision

PREMIUM POSTING SHEET

DEPARTMENT *No 23 Motor Assembly* WEEK ENDING *July 28, 1928*

		MONDAY							SATURDAY					
NUMBER	NAME	HOURS	POINTS	PREMIUM		PT HR	HO	HR	HOURS	POINTS	PREMIUM		PT HR	
93274	*John M Simms*	$8\frac{3}{4}$	615		.68	70			$4\frac{1}{2}$	310		.30	69	
87213	*H.S. Wilson*	$8\frac{3}{4}$	709	1	.38	81			$4\frac{1}{2}$	380		.83	85	
76322	*R Stone*													
13520	*S.G. Linn*													
12633	*Bob Smith*													
15462	*R.R Meyer*													
18621	*J. Thomas*													
9653	*S.K. Phelps*													

FIG. 104.—Premium posting sheet. This sheet is posted daily in the department for the benefit of the operators. It tells each workman his point hour and his premium for the previous day. A new sheet is started each week.

point hour of his department. For example, if the departmental supervision point hour is 80 for the week and the foreman receives \$1.10 base rate per hour and works 48 hr. per week, then his base earnings will be \$52.80 ($1.10 \times 48 = 52.80$). It is customary in most plants employing the point system to give all indirect labor the full premium (or equivalent to a 100 per cent Halsey). The premium then will be \$17.60, ($48 \times 80 = 3{,}840$ points at an 80-point hour); ($48 \times 60 = 2{,}880$ at a 60-point hour); $3{,}840 - 2{,}880 = 960$ indirect premium points: Premium earned is $\frac{960}{60} \times 1.10 = \$17.60$. The total earnings of the foreman for the week would then be $\$52.80 + \$17.60 = \$70.40$.

It is apparent that the more the direct labor earns the more the indirect labor will earn, and it should be so arranged that

the more effective the indirect labor the more the direct labor can produce and in turn the greater its earnings will be. This will be explained more fully in the following chapter.

Analysis Sheet.

The analysis sheet (see Fig. 105) is intended primarily to show supervision the total efficiency of direct and indirect labor, together with their cost, and to indicate in detail the reasons for any variations from standards previously set for the department.

The final figure, known as the supervision point hour, is the total measure of both efficiency and cost of direct and indirect labor in the department for the period and is used as a basis for determining the premium for all indirect labor and supervision for the department.

Column 1. *Date.* The analysis sheet is made out each day (in some departments, each week), and it is in the hands of the foreman by the noon following the day for which the data apply. This gives the foreman a picture of his operating efficiency while the details and peculiar conditions are fresh in his mind. It enables the executives to correct undesirable conditions soon after they are detected.

Column 2. *Equivalent number of employees on direct operations.* The sum of all the hours worked in the department is taken from the time cards for the department. This is 249.0 hr. for the day, Aug. 14, 1930. From this is subtracted the indirect hours worked in the department. This sum is taken from the department time summary sheet (Fig. 106). (It is $3{,}812 \div 60 = 63.5$.) Since 7.75 hr. have been allowed for the janitor budget, this will be subtracted from the total indirect labor: $63.5 - 7.75 = 55.75$ net indirect hr.

The direct labor is then the total minus the indirect or

$$249 - 63.5 = 185.5 \text{ direct hr.}$$

$185.5 \div 8 = 23.2$ equivalent number of employees on direct labor (8-hr. day).

Column 3. *Equivalent number of employees on indirect operations.*

Net indirect hours (see under column 2) $= 55.75$. $55.75 \div 8 = 6.98$.

Column 4. *Actual time in hours on direct operations* = 185.5 (see under column 2).

DEPT. NO. 23

ANALYSIS SHEET

DATE	EQUIVALENT NUMBER OF EMPLOYEES: ON DIRECT OPERATIONS	EQUIVALENT NUMBER OF EMPLOYEES: ON INDIRECT OPERATIONS	ACTUAL TIME IN HOURS: ON DIRECT OPERATIONS	ACTUAL TIME IN HOURS: ON INDIRECT OPERATIONS	ACTUAL TIME IN HOURS: TOTAL HOURS	DIRECT POINTS PRODUCED: OPERATORS ON STANDARD	DIRECT POINTS PRODUCED: OPERATORS NOT ON STANDARD (AT 60 PTS PER HOUR)	DIRECT POINTS PRODUCED: TOTAL DIRECT POINTS	DIRECT POINTS PRODUCED: DEDUCT FOR SCRAPPED WORK	DIRECT POINTS PRODUCED: NET TOTAL POINTS	OPERATORS POINT HOUR	ALLOWED TIME IN POINTS: LOST TIME DEPT RESPONSIBLE	ALLOWED TIME IN POINTS: LOST TIME DEPT NOT RESPONSIBLE	DEPT POINT HOUR	INDIRECT WORK IN MINUTES: SUPERVISION 2	INDIRECT WORK IN MINUTES: CLERICAL 17	INDIRECT WORK IN MINUTES: HANDLING 17	INDIRECT WORK IN MINUTES: MAINTENANCE 49	INDIRECT WORK IN MINUTES: SET-UP 28	INDIRECT WORK IN MINUTES: INSPECTION 28	INDIRECT WORK IN MINUTES: JANITOR	INDIRECT WORK IN MINUTES: TOTAL RATIO 36
AUG 14	23 2	6 98	185 5	55 75	241 25	13182	103	13285	126	3159	72	40	43	71	50 24	72 19	355 12	200 66	450 29	380 35		3149 33
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16 16a	17	18	19	20	21	22	23

DATE	TOTAL PAYROLL: FOR DIRECT LABOR	TOTAL PAYROLL: FOR INDIRECT LABOR	JANITOR BUDGET: POINTS USED (472)	JANITOR BUDGET: AMOUNT ALLOWED IN DOLLARS	JANITOR BUDGET: EXCESS	NET TOTAL INDIRECT COST	COST PER 1000 POINTS: ACTUAL COST PER 1000 DIRECT POINTS	COST PER 1000 POINTS: STANDARD COST PER 1000 DIRECT POINTS	COST PER 1000 POINTS: ACTUAL COST OF INDIRECT PER 1000 DIRECT PTS	COST PER 1000 POINTS: STANDARD COST OF INDIRECT PER 1000 DIRECT PTS	COST PER 1000 POINTS: TOTAL ACTUAL COST PER 1000 DIRECT PTS	COST PER 1000 POINTS: TOTAL STD COST PER 1000 DIRECT PTS	RATIO STANDARD COST TO ACTUAL COST	SUPERVISION POINT HOUR	ALLOWANCES - DEPT RESPONSIBLE: MACH BREAK DOWN OR TROUBLE	ALLOWANCES - DEPT RESPONSIBLE: WAIT FOR WORK	ALLOWANCES - DEPT RESPONSIBLE: CHANGE FROM ONE JOB TO ANOTHER	ALLOWANCES - DEPT RESPONSIBLE: MATERIAL TROUBLE	ALLOWANCES - DEPT RESPONSIBLE: POWER STEAM WATER OFF			ALLOWANCES DEPT NOT RESPONSIBLE: REST PERIOD	ALLOWANCES DEPT NOT RESPONSIBLE: FIRE DRILL	ALLOWANCES DEPT NOT RESPONSIBLE: HOSPITAL	ALLOWANCES DEPT NOT RESPONSIBLE: CONFERENCES VOTING ETC.	ALLOWANCES DEPT NOT RESPONSIBLE: POWER STEAM BEYOND CONTROL OF DEPT		
AUG 14	97 92	32 96	465	3 72		32 96	7 44	7 30	2 50	2 84	9 94	10 4	1 02	72	25	15								18		25		
24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52

FIG. 105.—Analysis sheet.

DEPARTMENTAL TIME SUMMARY SHEET

Summary of labor tickets for analysis sheet

Points from production at 60	103 =	103
Points for allowances:		
Machine breakdown	25	
Wait for work	15	
Power off	25	
Time in hospital	18	
		83
Minutes (points) for indirect labor		
Supervision	550	
Clerical	712	
Handling	1,055	
Maintenance	200	
Set-up	450	
Inspection	380	
Janitor	465	
		3,812
Total of production at 60, allowances and indirect, minutes		= 3,998
Total points produced	17,180	
Production at 60, allowance, indirect points	3,998	
Total direct points	13,182	
Total indirect (labor) points	3,812	

∴ 3,812 ÷ 60 = 63.5 total indirect hours.

Janitor work .... 465 min.

∴ 465 ÷ 60 = 7.75 hr.

63.5 − 7.75 = 55.75 net indirect hours.

Total pay roll on Aug. 14, 1930:

Supervision	$ 7.34
Clerical	6.50
Handling	8.80
Maintenance	1.69
Set-up	4.50
Inspection	4.13
Janitor	3.72
Total indirect cost	$36.68

FIG. 106.—Departmental time summary sheet showing the summary of time cards. These data are used for the analysis sheet.

Column 5. *Actual time in hours on indirect operations* = 55.75 (see under columns 2 and 3).

Column 6. *Actual time in hours, total hours.* This is the total of all indirect (minus any indirect labor on a budget, as janitor) plus direct labor hours in the department for the day. Columns 4 and 5 = 185.5 + 55.75 = 241.25.

Column 7. *Direct points produced, operators on standard.* The departmental summary sheet contains the total of all points produced by the department. This is 17,180. By subtracting from this total all production at 60, allowances, and indirect points, the difference will be the total direct points. 17,180 (total from the summary sheet, Fig. 106) − 3,998 (from summary sheet, Fig. 106) = 13,182 total direct points.

Column 8. *Direct points produced, operators not on standard (time turned in at 60 points per hour worked).* This is work for which there are no standards that apply. This is taken from the time cards and is shown on the departmental summary sheet to be 103 points or minutes.

Column 9. *Total direct points produced.* This is the sum of the column 7 + column 8 = 13,182 + 103 = 13,285.

Column 10. *Direct points to be deducted for spoiled work.* If an operator or the department is responsible for spoiling any work, the point standard for the spoiled work is subtracted from those produced. This is shown on the time cards and on the departmental summary sheet to be 126 points for the day.

Column 11. *Net total points.* This is the net amount of production turned out by the department and is equal to column 9 − column 10 = 13,285 − 126 = 13,159.

Column 12. *Operators' point hour.* This is an index of the speed of all direct operators in the department working on operations on time standards. It might be termed the operators' efficiency with 60 as a basis

$$= \frac{\text{points produced on standard}}{\text{hours used to produce the points}}.$$

Direct points produced = 13,182 (column 7). The time on direct operations from column 4 is 185.5, but this figure includes:

Production at 60 (column 8)	103
Lost time, department responsible (column 13)...	40
Lost time, department not responsible (column 14)	43
	186 points.

This sum (186 points) must be subtracted from 185.5 hr. to get the time actually used to produce the 13,182 points.

$$185.5 - (^{186}/_{60}) = 182.4 \text{ hr.}$$

$$\text{Operators' point hour} \ldots \frac{13{,}182}{182.4} = 72.$$

Column 13. *Allowed time in points, lost time, department responsible.* The department is held responsible for getting out production, and any delays due to or caused by the department will be charged against it under this allowance. Columns 39 to 45, inclusive, show some things for which the department is responsible. The data in columns 39 and 40 as obtained from the time cards and the departmental summary sheet = 25 + 15 = 40.

Column 14. *Allowed time in points, lost time, department not responsible.* This is the sum of columns 46 to 52 (from time cards and the departmental summary sheet):

$$\text{Column } 48 + \text{column } 50 = 18 + 25 = 43.$$

Column 15. *Department point hour.* This is an index of the speed of the department and includes everything with the exception of allowances, department not responsible (column 14)

$$= \frac{\text{net total points (column 11)}}{\text{direct hours (column 4)} - \text{lost time, department not responsible } \left(\frac{\text{column 14}}{60}\right)}$$

$$= \frac{13{,}159}{185.5 - (^{43}/_{60})} = \frac{13{,}159}{185.5 - 0.72} = \frac{13{,}159}{184.78} = 71.4 \text{ (use 71).}$$

Column 16. *Supervision minutes.* The amount of time that supervision was used for the day = 550 min. This is taken from the departmental summary sheet (Fig. 106).

Column 16*a*. *Supervision ratio.*

$$\frac{\text{Net total points (column 11)}}{\text{Supervision points (column 16)}} = \frac{13{,}159}{550} = 23.9 \text{ (use 24).}$$

Column 17. *Clerical.*

$$13{,}159 \div 712 = 18.5 \text{ (use 19).}$$

Column 18. *Handling.*

$$13{,}159 \div 1{,}055 = 12.45 \text{ (use 12).}$$

Column 19. *Maintenance.*

$$13{,}159 \div 200 = 65.8 \text{ (use 66).}$$

Column 20. *Set-up.*

$$13{,}159 \div 450 = 29.2 \text{ (use 29).}$$

Column 21. *Inspection.*

$$13{,}159 \div 380 = 34.6 \text{ (use 35).}$$

Column 22. *Janitor,* not used (on a budget).

Column 23. *Total ratio.* This is the ratio of direct points to one indirect point = sum of columns 16 to 22 divided into column 11 = 13,159 ÷ 3,347 = 3.93 (use 3.9).

Column 24. *Date,* same as column 1.

Column 25. *Total pay roll for direct labor.*

1. Find the total pay roll by adding the base earnings and the premiums for all direct and indirect labor in the department. This is taken from the time cards and is $127.18.

2. From the above sum subtract the total amount paid to indirect labor. $127.18 − $32.96 = $94.22.

3. Find the premium paid to direct labor from time cards. Premium equals $11.12. Add one-third of this to the amount found above and the sum will be the total direct pay roll. The one-third is added because the standard cost is calculated on the basis of 100 per cent premium.

$94.22 + \left(\frac{11.12}{3}\right) = 94.22 + 3.70 = \$97.92$ total pay roll for direct labor.

Column 26. *Total pay roll for indirect labor.* This is taken from time cards and summary sheet = $32.96.

Column 27. *Janitor budget, points used.* Taken from time cards and departmental summary sheet = 465 points.

Column 28. *Janitor budget, in dollars.* Taken from time cards and departmental summary sheet = $3.72.

Column 29. *Janitor budget, excess.* The difference of standard from actual. None in the above example.

Column 30. *Net total indirect cost.* This is equal to column 26 + column 29 = $32.96. Any excess in budgets such as an excess in the janitor's budget is added to column 26. Since there is no excess on this particular day, column 26 is equal to column 30.

Column 31. *Actual cost per* 1,000 *direct points*

$$= \frac{97.92 \text{ (total amount of direct pay roll, column 25)}}{13{,}159 \text{ (net total points, column 11)}}$$
$$= 0.00744 \text{ actual cost per direct point.}$$

multiplying by 1,000 = $7.44 actual cost per 1,000 direct points.

Column 32. *Standard cost per* 1,000 *direct points.* Taken from the standard set-up (see Fig. 110) as \$7.30.

Column 33. *Actual cost of indirect per* 1,000 *direct points*

$$= \frac{32.96 \text{ (net total indirect labor cost (pay roll) column 26)}}{13{,}159 \text{ (net total points, column 11)}}$$

$$= 0.002504 \text{ per point or } \$2.50 \text{ per } 1{,}000 \text{ points.}$$

Column 34. *Standard cost of indirect per* 1,000 *direct points.* \$2.84 (see set-up sheet for department, Fig. 110).

Column 35. *Total actual cost per* 1,000 *direct points.* Column 31 + column 33 = \$7.44 + \$2.50 = \$9.94.

Column 36. *Total standard cost per* 1,000 *direct points.* Column 32 + column 34

$$= \$7.30 + \$2.84 = \$10.14 \text{ (see Fig. 110).}$$

Column 37. *Ratio of standard cost to actual cost.*

$$\frac{\text{Column 36}}{\text{Column 35}} = \frac{10.14}{9.94} = 1.02.$$

Column 38. *Supervision point hour* = departmental point hour (column 15) × ratio standard to actual cost (column 37) = 71 × 1.02 = 72.

Column 39 to 45, inclusive. *Allowances, department responsible.* These data are taken from time cards and departmental summary sheet.

Columns 46 to 53, inclusive. *Allowances, department not responsible.* These data are taken from time cards and departmental summary sheet.

CHAPTER XII

THE POINT PLAN. A SYSTEM OF WAGE PAYMENT AND LABOR CONTROL

DETERMINATION OF STANDARD LABOR COSTS AND RATIOS

In practically all manufacturing departments there are two classes of labor employed: first, direct, sometimes called productive labor, and second, indirect, or nonproductive labor. Indirect labor does not change the form of the product, and its cost cannot be applied directly against particular units. It is a relatively simple matter to place productive operations on time standards and apply either piece-rate or some other form of incentive wage. But in most cases nonproductive labor cannot be given definite tasks so easily as can productive labor, and consequently it is more difficult to give wage incentives to this class of labor. It, therefore, may become necessary to base the bonus or incentive, if one is to be given to the nonproductive workers, on the output of the productive operators of that department. If, for example, one helper in the assembly department supplies material and takes away the assembled units for 15 men, then to a certain extent the output of these 15 productive men is dependent upon the services of the helper. If under standard conditions it requires just one helper for 15 men on this assembly work, then the more work these men do the more work the helper will have to do. So it would be fair and logical to give the helper a bonus based on the output of the direct or productive labor of the department. In a similar way, the foreman, supervisors, repair men, janitors, and other nonproductive labor could be rewarded for their increased effort.

Time Studies of Nonproductive Labor.

The question immediately arises as to the method of determining the number of productive workers that should be served by each nonproductive man. In the above example, how is it known that one helper will serve just 15 productive workers, assuming that both the helper and the productive workers are

working at 100 per cent efficiency? There is only one accurate way to determine this, and that is to make a time study of the work done by the helper. It is assumed that the productive labor is already working on jobs having time standards, and so the efficiency of these men can easily be found by referring to the records. The nonproductive time study of the helper would usually last a whole day or perhaps several days, and at the same time that the helper is being studied, all of the other nonproduc-

Operation: Janitor in department 23

Name and number: R. S. Miller, 26378 | Foreman: William Jones

Department 23 | Date: Oct. 7, 1929 | Observer: R. S. Gray

Begin: 7:30 a.m. | Finish: 12:00 | Elapsed: 4.5 hr.

Description of elements Divide into (1) supervision, (2) clerical, (3) handling, (4) maintenance, (5) set-up, (6) inspection, (7) janitor.	Stop-watch readings	Actual	Rating	With rest and delay allowance	Standard
Place ice in water fountain	6.10	6.10	65	69	7.02
Get can full of oiled sawdust from barrel in store room	9.50	3.40	50	50	2.83
Sprinkle over floor of storeroom and sweep entire room	18.35	8.85	60	60	8.85
Repair door lock and hinges (storeroom door)	40.12	21.77	45	45	16.30
Sweep entire shop floor	103.16	63.04	58	58	61.00
Move five loads of castings to building 39 (2,000 lb. to each skid load)	129.22	26.06	60	60	26.06
Personal	135.40	6.18	..	..	6.18
Dust foreman's office	148.31	12.91	50	50	10.75
Dust windows and exits of building (this is done only once each month) 1/24	169.46	21.15	45	45	15.85
Sweep loading platform	201.38	31.92	58	58	30.85
Oil conveyors in assembly line	236.17	34.79	58	58	33.60
Get office supplies for time clerk	252.10	15.93	60	60	15.93
Sweep stairways to second floor	260.20	8.10	55	55	7.42
Dispose of sweepings to can	262.43	2.23	40	40	1.48
Quit early	270.00	7.57	..	..	7.57

FIG. 107.—Nonproductive study.

tive workers in the department would be studied also. This is done as far as possible.

The superintendent of the department and the time-study observer would try to select a time for making this nonproductive study when the conditions in the department were about normal or standard, that is, when there was an average amount of productive and nonproductive work being done. This is desirable because the time studies that are made on these one or two days must be taken as representative for the week or month. After the studies are made, it is then possible to analyze them and determine the standards for the department.

Janitor	Maintenance	Lost time	Handling	Personal
7 02	16 30	..	26 06	6 18
2 83	33 60	7 57	15 93	
8 85				
61 00				
10 57				
0.66 (15 85 ÷ 24)				
30 85				
7 42				
1 48				

FIG 107*a*—Summary of nonproductive study of janitor.

The standard will be based on the units of productive work. Thus, if one handler spends 8 hr. or 480 min. per day and does all of the handling in the department and if there are 15 productive workmen working 120 hr. (15 × 8) or 7,200 min. per day, then the standard handling ratio for the department would be 7,200 ÷ 480 = 15. Or for every 15 min. of productive work, 1 min. of nonproductive handling would be required. This assumes that the 15 men as well as the helper work at 100 per cent efficiency.

It is desirable in some departments to divide all nonproductive work into the following classes:

1. Supervision.
2. Clerical.
3. Handling.
4. Maintenance.
5. Set-up.
6. Inspection.
7. Janitor.

For example, the foreman of the department may find it necessary, for the greatest efficiency, to spend the majority of his time on supervision, with some time devoted to clerical work and some to inspection. So the janitor may spend part of his time on janitor work, some on maintenance, and some on handling. Figure 110 shows the analysis made in a manufacturing and assembling department.

1. William Jones, foreman. Base rate 80 cts. per hour.
   - 250 min. at a 82-point hour = 342 points, supervision.
   - 180 min. at a 75-point hour = 225 points, clerical.
   - 50 min. at a 68-point hour = 57 points, inspection.
   - 480 — 624
2. H. J. Thomas, assistant foreman. Base rate 70 cts. per hour.
   - 220 min. at a 60-point hour = 220 points, supervision.
   - 190 min. at a 65-point hour = 206 points, inspection.
   - 70 min. at a 68-point hour = 79 points, clerical.
3. J. S. Story, helper. Base rate 50 cts. per hour.
   - 400 min. at a 70-point hour = 466 points, handling.
   - 80 min. at a 60-point hour = 87 points, janitor.
4. William S. Black, helper. Base rate 50 cts. per hour.
   - 420 min. at a 64-point hour = 448 points, handling.
   - 60 min. at a 60-point hour = 60 points, janitor.
5. R. S. Miller, janitor. Base rate 48 cts. per hour.
   - 300 min. at a 65-point hour = 325 points, janitor.
   - 110 min. at a 58-point hour = 106 points, maintenance.
   - 70 min. at a 54-point hour = 63 points, handling.
6. A. A. Williams, clerk. Base rate 55 cts. per hour.
   - 315 min. at a 70-point hour = 368, clerical.
   - 165 min. at a 65-point hour = 179, inspection.
7. Robert Clark, set-up man. Base rate 60 cts. per hour.
   - 312 min. at a 78-point hour = 406 points, set-up.
   - 119 min. at a 72-point hour = 143 points, maintenance.
   - 49 min. at a 65-point hour = 62 points, clerical.

FIG. 108.—Nonproductive summary and classification sheet (data taken from nonproductive time studies).

On the day that the nonproductive time studies were made, the time cards for the productive operations in department 23 were analyzed and the number of points at the different base rates were recorded in tabular form as indicated in Fig. 109. The horizontal line A indicates the base rates, and the numbers at C show the total points worked. For example, productive operators did 1,990 points at a base rate of 34 cts. per hour during the day of Oct. 7, 1929 (the day the nonproductive study was

made in department 23). Also, 780 points were produced at a base rate of 38 cts. per hour, etc. The direct-labor pay roll for the day was \$89.66, which checks with data in Fig. 109. The pay roll divided by the number of hours worked gives the "weighted base rate" or the average direct-labor wage per hour. This is shown to be \$0.43818 per hour for the department. By dividing this hourly rate by 60, the standard productive (or direct-labor) cost per direct point will be \$0.007303, as shown, or \$7.30 per 1,000 direct points.

A............	0.34	0.38	0.42	0.46	0.50	0.54
	360	300	480	126	480	125
	182	480	36	138	240	460
	62	....	480	120	480	78
	110	....	2,630	40	1,960	
	35	. .	25	1,250		
B............	46	....	.....	360		
	125					
	480					
	120					
	50					
	420					
C............	1,990	780	3,651	2,034	3,160	683

Hours

1,990 ÷ 60	=	33 2	×	0.34	=	11.28
780 ÷ 60	=	13.0	×	0.38	=	4.94
3,651 ÷ 60	=	60.8	×	0.42	=	25.56
2,034 ÷ 60	=	33.9	×	0.46	=	15.59
3,160 ÷ 60	=	52 6	×	0.50	=	26.33
663 ÷ 60	=	11.0	×	0.54	=	5.96

12,278 ÷ 60 = 204.6

Total direct-labor pay roll = \$89.66

$\frac{89.66}{204.6}$ = 0.43818 weighted base rate for productive labor.

Then $\frac{0.43818}{60}$ = 0.007303 standard productive cost per point.

= \$7.30 standard productive cost per 1,000 direct points.

FIG. 109.—Weighted base rates for productive labor.

Calculation of Nonproductive Labor Costs.

The table in Fig. 110 is divided into seven vertical columns with headings for each of the seven nonproductive classifications.

Department 23	Supervision		Clerical		Handling		Maintenance		Set-up		Inspection		Janitor	
	At 60-point hour	Rate per hour	At 60-point hour	Rate per hour	At 60-point hour	Rate per hour	At 60-point hour	Rate per hour	At 60-point hour	Rate per hour	At 60-point hour	Rate per hour	At 60-point hour	Rate per hour
Wm. Jones	342	0.80	225	0.80	...	...	...	...	...	...	57	0.80		
H. J. Thomas	220	0.70	79	0.70	...	...	...	...	...	...	206	0.70		
J. S. Story	...	...	...	...	466	0.50	...	...	...	...	...	...	87	0 50
Wm. S. Black	...	...	...	...	448	0.50	...	...	...	...	...	...	60	0 50
R. S. Miller	...	...	...	...	63	0.48	106	0.48	...	...	...	...	325	0 48
A. A. Williams	...	...	368	0 55	...	...	...	...	...	...	179	0.55		
Robert Clark	...	...	62	0.60	...	...	143	0.60	406	0.60				
Productive cards	...	...	...	...	36	0.50	...	...	38	0.55				
Total	562	0.762	734	0.615	1,013	0.499	249	0.550	444	0.601	442	0.653	472	0.486

Supervision . . . . . $\frac{12,278}{562} = 21.84$ (use 22) $\frac{1}{21.84}$ or $0.047205 \times \frac{0.762}{60} = 0.0005994$

Clerical . . . . . $\frac{12,278}{734} = 16.73$ (use 17) $\frac{1}{16.73}$ or $0.059772 \times \frac{0.615}{60} = 0.0006126$

Handling . . . . . $\frac{12,278}{1,013} = 12.12$ (use 12) $\frac{1}{12.12}$ or $0.082508 \times \frac{0.499}{60} = 0.0006861$

Maintenance . . . . . $\frac{12,278}{249} = 49.305$ (use 49) $\frac{1}{49.305}$ or $0.020281 \times \frac{0.550}{60} = 0.0001859$

Set-up . . . . . $\frac{12,278}{444} = 27.65$ (use 28) $\frac{1}{27.65}$ or $0.036160 \times \frac{0.601}{60} = 0.0003621$

Inspection . . . . . $\frac{12,278}{442} = 27.77$ (use 28) $\frac{1}{27.77}$ or $0.036010 \times \frac{0.653}{60} = 0.0003918$

0.0028379 total indirect labor cost per direct point
0.0073030 total productive labor cost per direct point
0.0101409 total standard direct and indirect labor cost per direct point

Total ratio . . . . . $\frac{12,278}{3,444} = 3.565$ (use 3 6)

\$ 2.84 standard indirect labor cost per 1,000 direct points
7.30 standard direct labor cost per 1,000 direct points
10.14 total standard direct and indirect labor cost per 1,000 direct points

Janitor budget

472 min. (points) at 0.486

Standard cost allowed $= \frac{472}{60} \times 0.486 = \$3\ 82$

FIG. 110.—Nonproductive ratios and standard costs.

The information from Fig. 108 is analyzed and placed in the proper column of the table in Fig. 110. For example, the foreman, William Jones, worked at an 82-point hour for 250 min. (that means that he did 342 points of work) on supervision during the day. So this figure 342 is placed in the table in Fig. 110 opposite William Jones' name and under the column headed Supervision. Since his base rate is \$0.80 per hour, that is placed opposite the number of points earned. In a similar manner the remainder of the nonproductive data is taken from Fig. 108 and placed in the table in Fig. 110. Then all of the vertical columns are added and the weighted base rate is found for each nonproductive classification. For supervision, 562 points were used during the day at an average rate of \$0.762 per hour.

From Fig. 109 the total productive points for the day of Oct. 7, 1929, was 12,278. The total nonproductive points for supervision for that day was 562 (Fig. 110), therefore the supervision ratio is equal to the productive (direct-labor) points divided by the nonproductive supervision points, or 12,278 ÷ 562 = 21.84 (use 22). This ratio means that for every 22 direct-labor points produced there will be required 1 min. (point) of supervision. In a similar manner the ratios are determined for the other nonproductive classes (see Fig. 110). The total nonproductive ratio for the whole department is found by dividing the total productive points by the total nonproductive points, or 12,278 ÷ 3444 = 3.565 (use 3.6), meaning that for each 3.6 productive points worked in the department there will be required 1 nonproductive point.

Referring to the calculations made on Fig. 110, if the supervision ratio is 22 then the reciprocal of this is 0.047205, meaning that for each productive point worked 0.047205 supervision nonproductive point will be required. If the average base rate per hour for supervision work is \$0.762, then the cost per minute would be \$0.762 ÷ 60 and the cost per direct point would be 0.047205 × 0.762/60 = \$0.0005994. In a similar manner, the cost can be found for all of the nonproductive classes, and the total of these is equal to \$0.0028379 for the nonproductive labor (since the janitor work is placed on a budget, this is not included).

The standard productive labor cost per direct point was found (see Fig. 109) to be \$0.007303. Therefore, the total cost per direct point will be the sum of the nonproductive-labor cost and the direct-labor cost per direct point, or \$0.0101409 (\$0.0028379

+ $0.007303). Since it is easier to speak and to think in larger sums of money, if the total is multiplied by 1,000 then the total standard labor cost per 1,000 direct points will be $10.14.

The nonproductive labor cost is one of the factors in a department over which a foreman has complete control. He is responsible for getting the production out for his department and he uses a certain amount of nonproductive labor to aid him. The standard ratios give the exact amount that has been allowed him. If he can in any way reduce the amount of nonproductive labor used, he will be able to lower his nonproductive pay roll and show an efficiency in this respect of over 100 per cent for his department. While, if he uses more nonproductive labor than the ratios call for, his indirect pay roll will be higher than the standard and his efficiency will be lower than 100 per cent. In either case the exact cause of this variation from the standard will be shown. It is apparent that the departmental analysis sheet presents a fairly complete picture of operating conditions in the department.

Summary.

The point plan of wage payment contains very few original features and it is not by any means a complete "system of control," for it deals, in most cases, with labor only. The value in using such terms as "point," "B," "manit," or "productive minute," should not be overestimated since many manufacturers are dealing with the same thing in setting standard times and they use the common term "standard minute" and base their operators' efficiencies on 100 per cent as the standard.

The point plan, however, has come into wide use within the past few years and it is used so successfully in many of our industries today that it deserves considerable study and thought. The system is not a made-to-order set of forms, methods, or rules, but combines many of the basic fundamental principles of management. For this reason it can be adapted to fit practically any set of conditions.

The features which make the point plan work out so well in practice and which bring about such large savings[1] to management might be summarized as follows:

[1] For specific illustrations see "Observation of the Bedaux System of Wage Payment," Policyholders Service Bureau, Metropolitan Life Insurance Co.

1. The point plan provides an incentive for direct labor.
   a. Guarantees a day rate.
   b. Based on stop-watch time studies.
      (1) Operators are rated and the standard is set on the basis of an average operator.
      (2) Proper allowances are made for rest and delays.
      (3) Normal time and "process allowances" are introduced to make the time standards more accurate.
   c. Posting sheets are used to inform the operator just what his point hour (efficiency) was for the previous day, as well as his bonus if he earned one.
   d. Guarantees not to cut the standards unless there is a change in the method.
   e. Determines the daily point hour (efficiency) of each workman, which makes it possible for the employees in different departments or plants to compare their standing. This feature is of value from a psychological point of view.
2. The point plan provides an incentive for indirect labor.
   a. The basis for this incentive is an over-all figure which combines the efficiencies of the direct labor in the department and the ratio of standard labor costs per point to the actual labor costs per point. This gives an incentive to all indirect labor to maintain a high direct-labor output and at the same time to keep the actual cost in the department as low as possible.
3. The point plan shows by means of the analysis sheet the conditions in the department and gives one figure the supervision point hour which is an over-all index of the general efficiency of the department. This supervision point hour is useful in making comparisons from week to week and in comparing one department or one factory with another.[1]

[1] The following paragraphs are taken from the report of a study which was made of the point plan as it is used by several leading manufacturers:
"The outstanding feature of the point system is that it works. It works because it is based on a combination of psychological factors which have a favorable reaction on the worker's mind; it offers incentive for extra work, it furnishes an accurate measuring device to show the worker when he has done well and when he has done poorly, and it enlists the administration in the person of the foreman in planning the work to avoid delays and interruptions.

Limitations of the Plan.

1. Cost.
   a. The cost of installing the point plan is likely to be rather high, since time studies are necessary, and then, after all, or practically all, direct labor is on the incentive plan a complete nonproductive study is made and the cost ratios are determined.
   b. If there is a very great change in the methods, or in the arrangement of the work, or if there is a considerable increase or decrease in output, it is very often necessary to make new nonproductive studies and determine new ratios. This, of course, is costly.
   c. It is necessary to have, in each department, men (departmental checkers) who supervise the collection of the data for making out the posting sheets, analysis sheets, etc. The usual time clerk takes care of the routine, but supervision is required.

The system is so devised that the direct worker helps himself, his fellow nonproductive worker, and his company by increasing his rate of output.

"The laborers are protected against individual hourly rate changes as well as against changes in the basic standards. The general level of wage rate is, of course, adjusted under this plan as under most others in accordance with market conditions, but the individual worker is not likely to be discriminated against by a foreman who tries to raise the rates of his favorites. With the posting-sheet information on premium points and rates of pay conspicuously posted each day, there was little opportunity for unfair discrimination in rates of pay. Ordinarily, all men in the same type of work received the same hourly rate of pay.

"The relative efficiency of laborers was so clearly indicated in a form that could readily be used that the management found it an aid in placing men where they would be most useful. The worker who had been placed in a job for which he was not suited showed a low point hour. He was shifted then to other work where he had a better opportunity for increased earnings. This change is likely to be made more quickly under the point system than under other conditions where a ready indicator of individual effectiveness is not available. Similarly, the worker was kept where he earned the most, since it was here that he was most valuable to the management.

"A worker of a low grade of intelligence may find it difficult to grasp the meaning of the point. Nevertheless, any laborer is capable of earning a premium if placed at a job for which he is fitted, and he will not fail to notice the additional earnings in his pay envelope, even though he may not comprehend the system.

"The management finds as many advantages in the application of the plan to productive workers as the laborer himself, for the company benefits

   d. From a glance at the posting sheet and the departmental analysis sheet, it is evident that considerable clerical work is required to handle all of these records, computations, and postings. Pay-roll calculations are also expensive items under this plan—no more so, however, than under some other incentive plans of wage payment.

2. In installing the point plan, little or no thought is usually given to the improvement of methods when the original time studies are made. It is generally conceded that a large part of the value of a time study results from the improvements that are made in methods or equipment, and if this is slighted there is undoubtedly a just criticism that could be made here.
3. As with many incentive plans of wage payment, more rigid inspection is required and there is a tendency for the quality of the work to be lowered. The point plan is not, however, so bad in this respect as some other incentive plans. The piece-rate plan, for example, puts a money value on each

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as much from the elimination of favoritism in setting wage rates as its employees. This elimination of favoritism saves unnecessary expense and fosters goodwill among the employees. The posting sheet shows the management clearly to what extent rates differ for the same work. If differences are evident, they can be investigated; while if they are not shown, the company may be losing money and stirring up discontent without knowing it.

"The posting sheet, moreover, tends to stimulate competition among workers and to arouse a feeling of pride in accomplishment. The competition may be not only between individuals in the same department but also between any two individuals in the plant, between whole departments, and even between different plants.

"The nonproductive worker gains from the operation of the point system. He is actually rewarded for increased effectiveness. He is made partly responsible for the rapid output of productive workers to whom he furnishes materials, supplies, and services. Each group gains from having the other group interested in its success.

"The foreman finds in the supervision premium a direct reward for improved efficiency and savings in total labor cost. His control of the men in his department is greatly facilitated by the facts which the point-system records present in clear form. The foreman is dealing with actualities and can base his decisions on them, whether they appear in the individual record of laborers or in the group summaries which show both effectiveness and economy of operation." *Harvard Business Rev.*, vol. VI, No. 2, p. 224, January, 1928.

piece, and this serves to emphasize the necessity for speed at any cost, which is not so much in evidence when the operator is producing points rather than dollars. The point plan has been modified in some plants to place an incentive on both quality and quantity, and where these two are used as a basis, the above criticism does not hold.

4. It is customary under the point plan for direct labor to be paid only 75 per cent of their earnings above a 60-point hour. The remaining 25 per cent is placed in a special fund from which the premium is paid to indirect labor (foremen, helper, janitors, etc.). There has been considerable criticism of this phase of the plan, since it is not at all unlikely for the direct labor to feel that part of their earnings are being given to the indirect labor. The B. F. Goodrich Rubber Company avoided this by modifying the Bedaux plan which they use. C. C. Shipman of the Goodrich Company[1] makes the following explanation:

"When the organization with which the writer is connected installed the Bedaux system, a direct departure was made from former Bedaux installations in that the premium paid to the indirect labor as an incentive was paid by the company and had no influence whatever upon the wages paid the direct labor. The amount of premium paid was based on premium B's (points) developed in the department and was a percentage of the base-rate earnings.

"At the time 'Bedaux' was installed, premium was paid only as an incentive for labor effectiveness; later it was found desirable to influence this premium by accomplishments on control of waste, machine maintenance, small tools, and supplies, quality of product, and cement and oils. Operating budgets were set on these various functions and the progress collected with the labor on the Bedaux analysis sheets, showing labor effectiveness and labor effectiveness modified by expense items. Premium is now paid on a modified application.

"The standards set are workable, are competitive between departments, and have changed the viewpoint of our foremen to that of managers. The scheme is psychological and has created interest which has resulted in the development of the operating personnel.

[1] GOTHE, OSCAR, Coordinating Wage Incentives and Production Control, *Trans. A.S.M.E.*, vol. 50, No. 10, MAN-50-8, p. 54, January–April, 1928.

"During the first year in which this system was used the above items were reduced to an appreciable level, resulting in savings to the company many times the cost of the premium paid."

5. In some plants the nonproductive labor is divided into a great number of subdivisions (see columns 16 to 23, Fig. 105) and an attempt is made to separate or classify, into these divisions, the work done daily. It is evident that this is a useless waste of time in many cases. For example, where a janitor does some work involving handling, some maintenance, and some work classed as janitor work it is quite often impractical for this man to stamp a time card when he changes from one kind of work to another. Much wasted effort might be saved if all indirect labor were combined and the total ratio used. In some plants this idea is now being adopted to an advantage.
6. The point plan does not control direct or indirect material costs, or total unit costs. Perhaps this is not desirable in some cases but it must be thoroughly understood that cost ratios on the analysis sheet are not total cost comparisons but only a partial analysis.[1]

[1] The following paragraphs are taken from the report of a study which was made of the point plan as it is used by several leading manufacturers:

"There are limitations to the adoption of the plan, however. First, there must be good management, at least at the top, which can lead and inspire those beneath. If one seeks a panacea for industrial ills and is unwilling that it should require effort on his part, he should leave the point system alone.

"The second limitation to the use of the system seems to be the cost of time studies. If a company does not have a large volume of business to absorb the engineering costs involved, it may find it more economical to try a less effective method. Again, the cost is likely to be too high for a company with many unlike operations and thousands of standards to be set, even if the total volume of business appears to be adequate.

"In plants in which the speed of production can be adequately controlled by the speed at which the conveyor system of the assembly line is regulated, an incentive wage system and engineering standards for work may not be required.

"Perhaps the most striking feature of the system from a general point of view is its flexibility. A representative of a large company stated that 'the system is so broad in meaning and the application can be so differently applied' that a resumé of his complete experience would be too long to embark upon. This flexibility is a source of strength. Instead of a plan that is forced upon a management without a change, point-system principles are offered management as tools to be developed and applied as the needs of the particular case and men require." *Harvard Business Rev.*, vol. 6, No. 2, p. 230, January, 1928.

CHAPTER XIII

MANUFACTURING COSTS

Manufacturing transforms raw material into finished products through the use of labor and equipment. For example, in the packing industry the live animal would be considered the raw material and the marketable cuts of beef and pork the finished product; while in the machine-tool industry, steel, brass, and cast iron are the raw materials from which the finished machines are made. Since manufactured products are, in general, sold in a competitive field, and since economy in production is of primary importance, some method of finding costs must be developed.

The earliest cost systems to be used were simply records of labor, material, and overhead expenses that entered into the production of an article. The total cost was calculated, in most cases, after the manufacturing operations were all completed. Such a cost system gives only a historical record. It is desirable to have this information, but to be of greatest value, costs should be available for measuring and controlling the operating efficiency of the plant from day to day. Costs should be considered as a tool to be used by management in the economical operation of a factory.

This conception of costs as a measuring stick for management has led to the development of standard costs. It is common practice now to set standards and predetermine factory costs before the product is started through the manufacturing operations. With such standard costs available the management then has something against which to measure actual costs. If these costs are found to run above the standard, it is known at once and action can be taken to correct the situation, whereas historical costs would not be available until the end of the period and would be of little value for control purposes.

Even though the accounting system shows that the firm as a whole is making a profit for the year, it is desirable to know which of the products manufactured bring a profit, and which a loss, to

the company. Accurate cost analysis is needed for this purpose as well as to form the basis for fixing the selling price of the manufactured product.

Material, labor, and equipment are employed only when they "pay their way" in the factory. Accurate costs of the proper kind show up those items which are not contributing their share and make it easy to prevent uneconomic practices.

Elements of Factory Costs.

The finished product is the result of one or more manufacturing operations. The factory cost of this product is defined as the total cost of manufacturing it complete. This cost is made up of (1) direct-material costs, (2) direct-labor costs, and (3) the factory expense (sometimes called burden or overhead).

Direct Material.

By direct material is meant the material entering directly into the finished product in such a manner that it can be determined accurately as to cost and amount and can be charged to a specific production order. In the case of a carpenter's hammer, for example, the amount of steel used for the hammer head and the amount of wood used for the handle can be accurately determined. These two material costs can be charged against a particular hammer or lot of hammers. However, the cost of the paint used in the spray gun for stenciling the small trade-mark on the hammer handle would be more difficult to determine, since not only hammers but saws, axes, and other hand tools are marked with the same stencile and from the same spray gun in the course of a day. It is evident that the determination of the cost of the paint actually used on any one hammer would involve more work than the paint itself was worth. Also, the cost of the oil burned in the heat-treating furnaces would be difficult to determine for any one tool, because of the variety of products passing through the furnace each day. Lubricating oil for the machines, cotton waste, etc., are other examples of indirect materials.

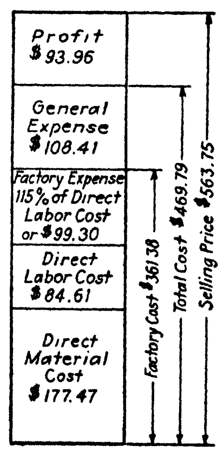
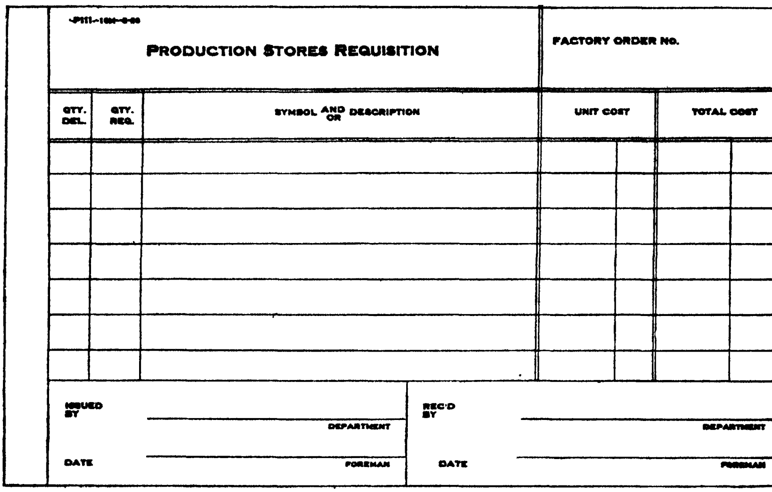


FIG. 111.—Elements that go to make up the selling price of a manufactured product.

Therefore, those materials that indirectly affect the cost of a product, or are so small in magnitude that it is impractical to charge them directly to a specific product, would be classed as indirect materials and would enter into the cost of the article through the item of factory expense. It is desirable to allocate as much material as possible directly to the specific product, since this tends to make the cost determination for the product more accurate. Even if the indirect materials described above


PRODUCTION STORES REQUISITION

FACTORY ORDER NO.

QTY. DEL.	QTY. REQ.	SYMBOL AND OR DESCRIPTION	UNIT COST	TOTAL COST

ISSUED BY — DEPARTMENT
DATE — FOREMAN
REC'D BY — DEPARTMENT
DATE — FOREMAN

FIG. 112.—A stores issue. (*Courtesy of the Caterpillar Tractor Company.*)

cannot be charged directly against a specific product, they can very often be applied to the product cost by prorating this expense over the products made in the department, rather than throwing all indirect material costs into the factory expense and then distributing that over all products manufactured in the entire plant.

Stores Issue.

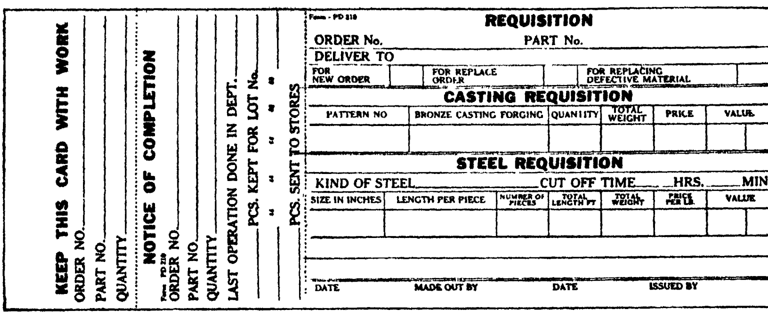
A stores issue signed by the foreman, or some other designated person, is the authority for issuing material from the storeroom for production. The order number appears on each stores issue, usually in the upper right corner, and through this number the cost of the material is charged against the proper order by the cost department. Figure 113 shows a combination stores issue, notice of completion, and identification tag. This form is

used for requisitioning castings as well as steel stock. When it is used as a stores issue for bar stock, it also serves as the time card for direct labor for the "cut-off" operation. A specification sheet as well as a detail drawing is attached to this stores issue.

Indirect material is not charged against any particular order but this cost goes into the factory expense account and is distributed over the entire production of the factory in a manner to be explained later.

Direct Labor.

Direct-labor cost is represented by the wages paid to those working directly on the product. The wood-lathe operator who turned out the hammer handles mentioned above produces a



KEEP THIS CARD WITH WORK
ORDER NO.
PART NO.
QUANTITY

NOTICE OF COMPLETION
Form PD 218
ORDER NO.
PART NO.
QUANTITY
LAST OPERATION DONE IN DEPT.
PCS. KEPT FOR LOT No.
PCS. SENT TO STORES

Form - PD 218
REQUISITION

ORDER No. PART No.
DELIVER TO
FOR NEW ORDER | FOR REPLACE ORDER | FOR REPLACING DEFECTIVE MATERIAL

CASTING REQUISITION

PATTERN NO	BRONZE CASTING FORGING	QUANTITY	TOTAL WEIGHT	PRICE	VALUE

STEEL REQUISITION

KIND OF STEEL ____ CUT OFF TIME ____ HRS. ____ MIN.

SIZE IN INCHES	LENGTH PER PIECE	NUMBER OF PIECES	TOTAL LENGTH FT	TOTAL WEIGHT	PRICE PER LB.	VALUE

DATE MADE OUT BY DATE ISSUED BY

Fig. 113.—Combination of stores issue, notice of completion, and identification tag. (*Courtesy of the Gleason Works.*)

particular item and his wages while working on this job can be charged directly to the product made. However, the wages paid to the janitor who cleans up around the wood lathes as well as around the other machines in the building would be classed as indirect-labor cost. This labor cannot be easily associated with any particular hammer handle or lot of handles. Indirect-, sometimes called nonproductive-, labor costs go into the factory expense account and are distributed over the total factory output.

Time Cards.

In most factories direct-labor costs enter into the cost of the product through the use of time cards. A card is made out for each employee, and in many systems separate cards are required for each job or operation. Each card provides space for recording the beginning and ending time for each job and from this the

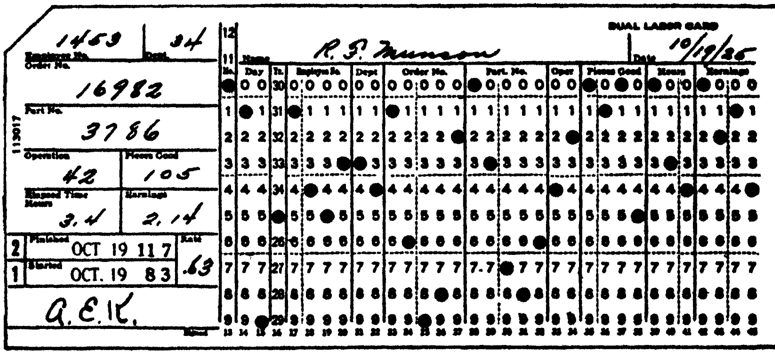


FIG. 114.—Time card for use with a tabulating machine. This card carries both the original written information and the corresponding punched holes. (*Courtesy of the International Business Machines Corporation*)

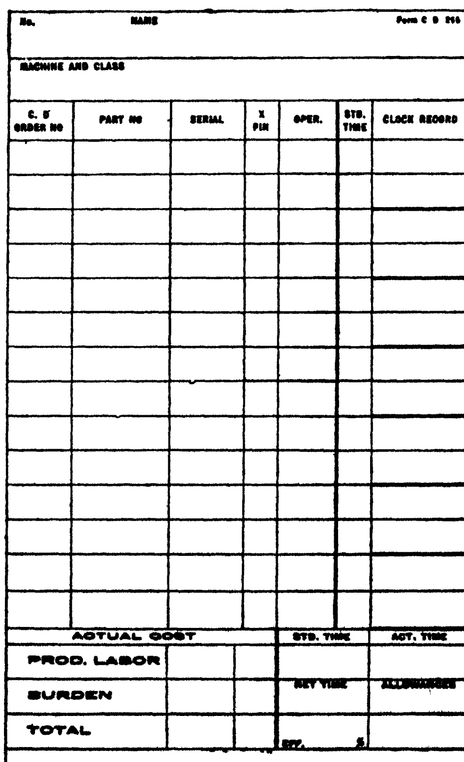


FIG. 115.—Time card for a day's work. This card was designed for use in the cutter-head grinding department where the operator ordinarily completes several different jobs in one day. (*Courtesy of the Gleason Works.*)

elapsed time is found. The sum of elapsed time as taken from the time cards for the day would, of course, equal the number of hours that the employee worked that day. The time cards are sorted by the cost department according to order numbers and in this way direct-labor costs are charged to the proper accounts. Time cards may serve a second function and be used as the basis for pay-roll calculations. In some systems the total time as taken from the time cards is used to check the totals on the pay-roll time cards which are stamped with the exact time of beginning work in the morning and again in the evening at quitting time.

Figure 114 shows a very common type of time card with space for writing in the necessary information, and also carrying corresponding punched holes. By the use of sorting and tabulating machines and these cards it is possible to obtain the total labor costs mechanically. Figure 115 shows a different type of time card designed for a day's work.

The time of beginning and ending an operation or job is usually marked on the time card by means of a clock-driven, numbering mechanism which prints the year, month, day of the month, and hour and minute of the day. The elapsed time is obtained by ordinary subtraction. In the case of straight day wage, the elapsed time multiplied by the hourly rate gives the labor cost for the job.

It is clear that both direct-material and direct-labor costs can be accurately allocated to each finished product or each production order, and consequently each will bear its true share of these two costs.

Factory Expense.

There is a third class of costs that enters into the total factory cost of a product. This is called factory expense. Such costs as depreciation on buildings, tools and equipment; repairs; cost of power, light, and heat; indirect material; indirect labor; rent, insurance; etc., are certainly costs of production even though they cannot be specifically charged against any one production order. In fact, such expenses as rent, depreciation, taxes, insurance, and the like are present whether the factory operates at low or at full capacity.

Since the factory is built and maintained for manufacturing purposes, the finished product leaving the plant must bear its share of these expenses.

Methods of Distributing Factory Expense.

There are many different methods for distributing factory expense but the most important ones might be listed as follows:

1. Direct material.
2. Direct labor.
3. Man-hours.
4. Machine-hour rate.

Distribution on the Basis of Direct Material, or Output.

The total factory expense for a given period might be distributed evenly over the total output of the factory for the same period. This method would be satisfactory only for industries manufacturing a single product such as, cement, lumber, and brick plants.

Assume that for a given period the

Total direct material charge	= $100,000.00
Total factory expense	= 85,000.00
Percentage of factory expense to indirect material = $85,000 ÷ $100,000	= 85 per cent

This percentage will be applied to a particular order or lot in the following manner;

Direct-labor cost for the job	= $300.00
Direct-material cost for the job	= $1,000.00
Factory expense = 85 per cent of direct material	= 850.00
Total cost	= $2,150.00

In cases where the expenses do not vary in direct proportion to the output, some other method of distributing expense must be used. Since most industrial concerns manufacture more than one product and since the relation of expense to output is not constant, the distribution of factory expense by this method is seldom used.

Distribution on the Basis of Direct Labor.

The method of distributing factory expense on the basis of direct-labor cost is perhaps the most widely used of any, due mainly to its simplicity of application. This plan is based on the assumption that factory expense chargeable to any one job varies as the direct labor expended on the job.

Thus, if the following data are assumed for a given period:

Total direct-labor charge	= \$50,000.00
Total factory expense	= \$60,000.00
Percentage of factory expense to direct labor	$= \dfrac{\$60,000}{\$50,000}$

= 120 per cent or \$1.20 for each dollar of direct-labor pay roll.

The percentage is calculated from the cost data from the preceding period. In industries where the relationship between factory expense and direct labor does not vary greatly from period to period, it is customary to apply the same percentage for an entire year, rather than calculate a new percentage figure each period.

The method of distributing factory expense as a percentage of direct labor is at best only approximate and can be used satisfactorily only in those departments or industries where the wage rates are fairly uniform and where the nature of the work, processes, and equipment is similar. There are several serious defects to the use of this method of distributing factory expense, one of the most serious being the difference in the cost of various pieces of equipment and machinery used in the plant. It is evident that an operation performed on a large surface grinder should be charged with a greater share of the factory expense than an operation taking an equal length of time but performed on a small drill press. There is no definite relation between the cost of operating equipment and direct-labor cost.

In the case of two workmen using equipment of equal value but working with different degrees of skill and efficiency, one may perform an operation in 5 hr. and receive 70 cts. per hour, while the other may take 7 hr. to perform his operation and receive 50 cts. per hour for it. The factory expense would be the same on each of these jobs, where the expense is distributed on the basis of direct-labor cost. No provision is made by this method to distribute the expense either in proportion to the cost of operating the equipment or on the basis of the time that the equipment is in operation.

However, if machinery and equipment of similar size and nature are located together in separate departments, it is often more satisfactory to determine a percentage figure for each of the departments and then prorate the expense incurred in each department over the work performed in that department on the basis of direct-labor cost as explained above.

Furthermore, during periods when business is decreasing, the percentage of expense will increase, since the total factory expense will not decrease in proportion to the decrease in labor used. This will result in adding a greater expense charge to the prime cost of the product; and in turn this will show an increase in manufacturing costs when the fault is really due to a lack of orders and not due to inefficiencies in the factory.

Distribution on the Basis of Man-hours.

This method is similar to that of distributing factory expense as a percentage of direct-labor cost. It differs, however, in that the basis is hours of direct labor instead of cost of direct labor.

The following example will illustrate this method. Assume that the total direct labor used for the period is 80,000 hr. and the total factory expense is $48,000. Then the ratio of expense to man-hours is $48,000/80,000 = $0.60 per man-hour.

In many cases, time forms a better basis for distributing expense than does either direct-labor cost or direct-material cost. However, the man-hour method, like the two others described, fails to take into consideration the value and size of the machinery and equipment used in performing the operations.

Distribution of Factory Expense by Machine-hour Rate.

On analysis of the elements that enter into factory expense, it is found that many of these elements can be definitely assigned to the particular machine. Many of these items are created because the particular machine is used and depend in amount upon the nature of the machine. There is greater expense incurred from the operation of an automatic screw machine than from a small bench lathe. In either case it is possible to analyze the expenses of operation into definite measurable factors. For instance, the screw machine would occupy several times as much floor space as the bench lathe. The cost of lighting, heating, and ventilation, as well as the land and building charges, would vary directly with the floor space occupied by the machine.

There are, however, certain cost items that will necessarily be prorated over the equipment in the whole department. The cost of supervision, tool-room attendents, departmental supplies, etc., are examples of expenses falling into this class.

Power is a cost that can be assigned definitely to the individual machine. The screw machine will require many times more power than the bench lathe. The exact amount of power consumed by each machine might be determined by placing meters on the machine, but that would not be practical in most cases. A close approximation can be obtained on the basis of rated horsepower of the machine, or of the motor, if individual motor drive is used.

Depreciation, taxes, and insurance on each machine can be determined with a considerable degree of accuracy, and definitely allocated.

If each item of expense is carefully studied and charged against each machine or production center, the total of these items divided by the estimated number of hours that the machine will run during the period will give the machine-hour rate.

The greatest inaccuracy in the machine-hour rate results from the uncertainty as to the number of hours that a machine will be used during the period. If the machine operates just the estimated number of hours, the machine-hour rate will provide for all expenses incurred. However, if the machine is not used so many hours as estimated, there will be some expense that will not be charged off at the end of the period; while if the machine is used a greater number of hours than estimated, too much expense will be charged off and there will be a surplus created at the end of the period.

Adjustments can be made by means of a supplementary rate which is set up to correct for inaccuracies in the machine-hour rate. Adjustments can also be made by setting up a special account to take care of the differences. These variations in expenses as provided by the regular machine-hour rate will tend to balance themselves over a period of time. Revision in the machine-hour rates would be made at definite periods.

Calculation of the Machine-hour Rate.

In order to illustrate the application of this method, the machine-hour rate will be calculated for a group of Milwaukee horizontal milling machines. Three of these machines are required for the manufacture of the flywheel clutches, as indicated in Prob. 6 on page 274. The dimensions of the production center are shown in Fig. 116. The production center includes

floor space for the machine, skid platforms, working area, and half of the aisle leading up to the machine.

The form shown in Fig. 117 is very convenient for use in tabulating the information needed in calculating the machine-hour rate. An explanation of the method used in determining the data for each of these columns will be made here:

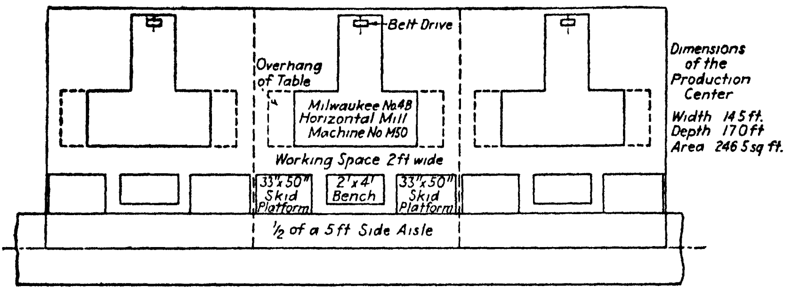


FIG. 116.—Layout for a group of three Milwaukee horizontal milling machines, showing the size of the production centers.

Column 1. Machine number: M50 (see page 324 of Appendix A).
Column 2. Name of machine: Milwaukee horizontal mill.
Column 3. Overall dimensions of machine: 12.25 by 9.5 ft.
Column 4. Rated horsepower of machine: 15.
Column 5. Present value (new): $4,440.00.
Column 6. Scrap value of machine: $444 (estimated as 10 per cent of cost).

Column 7. Estimated life of machine in years: 15 (see Appendix C).

Column 8. Area of production center: 246.5 sq. ft. This area is determined from the layout of the factory (see Fig. 116).

Column 9. Number of machines in group: 3. The number is taken from the actual layout of the factory.

Column 10. Hours in use per month per group: 481. This figure is estimated from past records and from estimated orders unless the output is accurately known. Since the milling machines are used for the manufacture of the flywheel clutches in Prob. 6, the time required is known from the calculations made in Fig. 19 of page 36.

Column 11. Area covered by the group: column 8 $\times$ column 9 = 246.5 $\times$ 3 = 739.5 sq. ft. (use 740).

Column 12. Floor area chargeable to the group of machines: The area shown in column 11 is the space occupied by the group of machines, but part of the main aisles, foremen's and superintendent's offices, storerooms, etc., must also be charged to this group.

	Square feet
Total area of shop	= 55,450.
Total area of production centers	= 33,402.

$$\text{Floor-space factor} = \frac{55,450}{33,402} = 1.66.$$

Floor area chargeable to the group of milling machines = 740 × 1.66 = 1,228 sq. ft.

Column 13. Horsepower-hours per month per group: If the electric power used in the plant is metered to each department from the power-plant switchboard, it is possible to prorate the average power consumption in the department over the machines in that department. This distribution might be made on the basis of the horsepower rating of the motors used to drive each machine or on the basis of the rated horsepower (recommended by the manufacturer of the machine) of the machines if group drives are used.

If the power used by each department is not metered separately, it is necessary then to prorate the total power consumption for the plant over all the machines in the plant.

If for example, the average power load for the department is 325 kw. or 436 hp. (1 hp. = 0.746 kw.), and the total of all motors in the department is 710 hp.

The average consumption of power = $^{436}/_{710}$ = 0.614.

Therefore, the 15-hp. motor uses only (15 × 0.614) 9.21 hp. on the average.

Horsepower-hours per month per group = 9.21 × 481 = 4,430.

Column 14. Present value per group: (column 5 × column 9) = 4,440 × 3 = $13,320.00.

Column 15. Power cost per month per group: Assuming the power cost to be 1.6 cts. per kilowatt-hour, or 1.194 cts. per horsepower-hour, the power cost for the group of three milling machines for the month would be

$$4{,}430 \times \$0.01194 = \$52.89.$$

Column 16. Depreciation per month per group: Cost of the three milling machines new = $13,320.00.

Scrap value of the three milling machines = $1,332.00.

Estimated life of machines in years = 15.

Depreciation by the straight-line method, that is an equal amount each year:

$$\frac{13{,}320 - 1{,}332}{15 \times 12} = \$66.60 \text{ per month.}$$

Column 17. Supervision and miscellaneous charges per month per group: Cost of factory supervision and indirect labor, such as foreman, set-up men,

helpers, time clerks, tool-room attendents, etc.	= $4,270.00
Miscellaneous supplies, oil waste, etc.	= 235.00
All minor expenses not otherwise allocated	= 185.00
Total	= $4,690.00

These charges are distributed over the number of hours that the machines in each group operate during the period. For greater accuracy the cost items in this division might be further subdivided and applied to the machines in the group on more appropriate factors.

Total estimated hours that all machines in the plant will operate per month (total of column 10) = 47,860 hr.

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
Machine No.	Name of machine	Overall dimensions of machine	Rated hp.	Present value (new)	Scrap value	Estimated life in years	Area of production center	Number of machines	Hours in use per month per group	Area covered by group	Floor area chargeable to group	Hp.-hours per month per group	Present value (new) per group	Power cost per month per group	Depreciation per month per group	Miscellaneous charges per month per group	Space charge per month per group	Machine value charge per month per group	Total charge per month	Hourly rate	Rounded machine-hour rate	Machine No.
M1	Duplex automatic horizontal mill																					M1
L2	Chucking lathe, No. 6A model																					L2
M3	Vertical boring mill 36 in. Bullard																					M3
A4	Vertical chamfer and cut-off automatic																					A4
A5	Automatic screw machine, Cleveland																					A5
D6	Five-spindle automatic drill, Detroit No. 2																					D6
A7	Automatic screw machine Gridley 4-spindle																					A7
A8	Automatic screw machine, Cleveland																					A8
L9	Automatic lathe, Fay 14 in.																					L9
D10	Heavy-duty drill, Foote-Burte																					D10
D11	Special multiple drill																					D11
D12	Multiple drill, Nacto 22-spindle																					D12
D13	Multiple drill, Nacto 16-spindle																					D13
D14	Plain drill, Cincinnati Bickford																					D14
D15	Radial drill, Cincinnati Bickford																					D15
D16	Sensitive drill, Avey 1-spindle																					D16
D17	Sensitive drill, Allen 2-spindle																					D17
D18	Sensitive drill, Avey 1-spindle																					D18
L19	Turret lathe, Warner & Swasey No. 2A																					L19
L20	Turret lathe, Warner & Swasey No. 3A																					L20
L21	Turret lathe, Jones & Lamson 2-spindle																					L21
L22	Turret lathe, Warner & Swasey																					L22

S23	Cut-off saw, Newton No. 199 circular																					S23
D24	Sensitive drill, Allen 2-spindle																					D24
D25	Tapping drill, Cinn. Bickford																					D25
D26	Horizontal drill, Avey 2-spindle																					D26
G27	Cylindrical grinder, Norton 14 by 72 in.																					G27
G28	Cylindrical grinder, Norton 20 by 96 in.																					G28
G29	Cylindrical grinder, Norton																					G29
G30	Surface grinder, Blanchard																					G30
H31	Gear hobber, Barber Colman No. 12																					H31
T32	Trip hammer, Bradley 75-lb.																					T32
B33	Keyseating broach, LaPointe No. 3 single																					B33
B34	Keyseating broach, LaPointe No. 4 single																					B34
L35	Centering lathe, Whiton																					L35
L36	Engine lathe, Le Blond																					L36
L37	Engine lathe, American																					L37
L38	Engine lathe, Le Blond																					L38
L39	Engine lathe, Le Blond																					L39
L40	Engine lathe, American																					L40
L41	Hand-screw machine, Warner & Swasey																					L41
L42	Hand-screw machine, Southworth No. 4																					L42
L43	Special lathe, Lo-Swing																					L43
L44	Crankshaft lathe, Lodge & Shipley																					L44
M45	Hand mill, Whitney No. 6																					M45
M46	Plain mill, Brown & Sharpe																					M46
M47	Plain horizontal mill																					M47
M48	Horizontal mill																					M48
M49	Key-seat milling machine																					M49
M50	Plain horizontal mill, Milwaukee																					M50
P51	Vertical hydraulic press Logeman 50-ton																					P51
P52	Punch press, Williams & White																					P52
P53	Power shears, Niagara																					P53
H54	Fellows gear shaper																					H54
P55	Punch press consolidated, No. 5 inclined																					P55
X56	Bench																					X56

FIG. 117.—A convenient form for calculating machine-hour rates.

Charge per hour = \$4,690.00/47,860 = \$0.098.

The number of hours that the group will operate per month is 481. Therefore, 481 × \$0.098 = \$47.14.

Column 18. Space charge per month per group: This includes the land and building charges, the heating and lighting charges, and other charges that might be charged off on the basis of floor area without great error.

The computations are as follows:

Cost of land	=	\$ 12,000.00	
Cost of buildings	=	\$485,000.00	
		\$497,000.00	\$497,000.00
Transmission equipment	=	15,000.00	
Furniture and fixtures	=	18,525.00	
Miscellaneous equipment	=	12,400.00	
		\$45,925.00	45,925.00
Total cost of plant less machinery	=		\$542,925.00

Interest on \$542,925 at 6 per cent, per month	=	2,714.62
Taxes on \$542,925, per month	=	904.87
Insurance on plant (\$542,926–\$12,000), per month	=	2,880.00
Water, heat and light, per month	=	1,225.00
Depreciation on buildings, per month	=	1,938.00
Depreciation on equipment, per month	=	415.00
Total	=	\$10,077.49

Then the space charge per square foot per month is

$$\frac{\$10{,}077.49}{64{,}750 \text{ (total floor area of plant)}} = \$0.1556.$$

Floor area chargeable to the group of milling machines = column 11 = 740 sq. ft.

Therefore, the space charge = 740 × \$0.1556 = \$115.14.

Column 19. Machine charge value per month per group: This charge includes interest, taxes, insurance, and repairs that can be charged directly against the production center. The distribution is made on the basis of the value of the production center.

Value of the three milling machines = \$13,320.00

Interest on \$13,320 at 6 per cent, per month	=	\$66.60
Taxes on \$13,320, per month	=	22.20
Insurance upon \$13,320, per month	=	16.65
Repairs and maintenance, per month	=	11.10
Total	=	\$116.55

Column 20. Total charge per month for the group:

a. Power cost, from column 15	=	$52.89
b. Depreciation, from column 16	=	66.60
c. Supervision and miscellaneous charges, from column 17	=	47.14
d. Space charge, from column 18	=	115.14
e. Machine value charge, from column 19	=	116.55
Total charge per month per group	=	$398.32

Column 21. Machine-hour rate: The hourly rate is found by dividing this total monthly charge by the total estimated time that the machines in the group will run per month.

Thus for the group of milling machines, No. M50, this charge is 398.32/481 = $0.8281.

Column 22. Rounded machine-hour rate: In order to make the machine-hour rate more usable, the computed rate is rounded off to the second decimal place. This does not affect the accuracy of the rate, since approximations were used in the determination of some of the original data. The rounded machine-hour rate, then, is $0.83. This means that for every hour the machine is used a charge of $0.83 should be made against the work done on the machine. This charge plus the direct-labor cost and the direct-material cost will then equal the total factory cost of the job or operation.

Depreciation.

Buildings, machinery, and equipment depreciate because of wear and tear, obsolescence, and inadequacy. If equipment is properly used and well cared for, the wear and tear can be minimized, but in time these assets will have to be replaced. Depreciation results from obsolescence caused by the invention and development of newer and more economical machines and processes which supplant the present ones even before they are worn out. Inadequacy is the inability of assets to meet the demands made upon them. This is usually caused by expansion in business, and as a result the equipment may have to be discarded before it is worn out.

The elements that normally enter into the depreciation charges are (1) first cost, (2) estimated useful life, and (3) scrap value. For example, the Milwaukee milling machine already referred to, cost $4,440 installed, and it was estimated that this machine would last 15 years, at the end of which time it would have a scrap value of $444. It therefore becomes necessary each year to charge off a certain part of this $4,440 so that by the end of 15 years the machine will be depreciated to its scrap value.

The simplest and by far the most widely used method is to charge off an equal amount each year, as:

$$\text{Annual depreciation} = \frac{\text{First cost} - \text{scrap value}}{\text{Estimated life in years}}$$
$$= \frac{\$4{,}440.00 - \$444.00}{15} = \$266.40.$$

It should be thoroughly understood that depreciation is a real part of factory expense and must be considered as such in

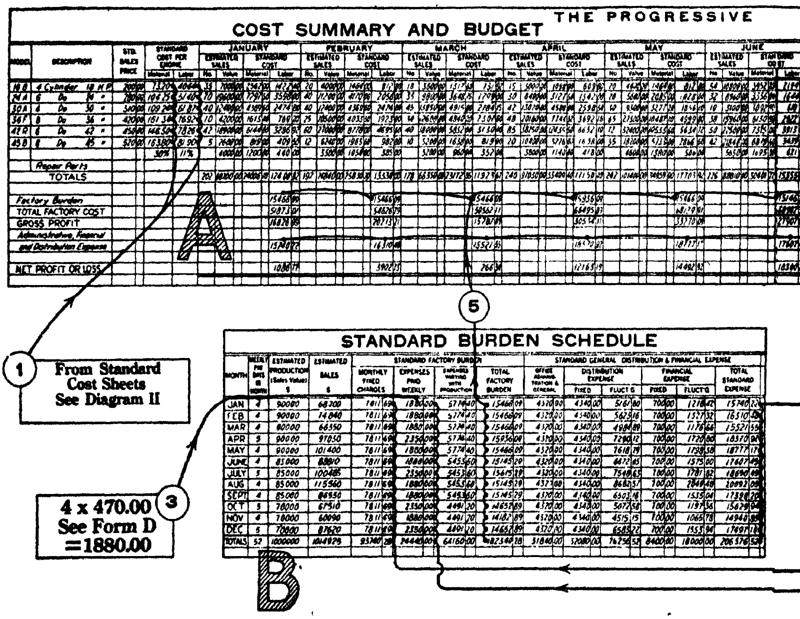


FIG. 118.—Diagram I illustrating use of

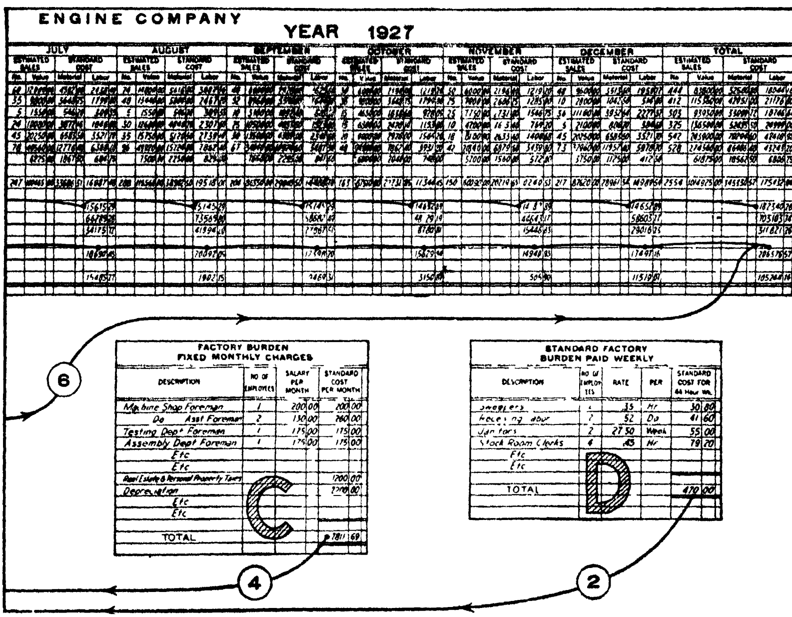
determining factory costs. Due to a lack of space a complete discussion of depreciation and the various methods of charging it off cannot be given here.[1]

The depreciation data included in Appendix C give the estimated length of life for the various kinds of equipment. Since the length of life of equipment depends upon a number of widely variable factors, it is evident that differences of opinion may enter into these estimates.

[1] For further information on depreciation see E. A. Saliers, ed., "Accountants' Handbook," p. 471.

Standard Costs.

Standard costs have come into use in this country in recent years and this system owes much of its success to the fact that it requires management to look into the future. In setting up standard costs, a detailed analysis must be made of the elements that enter into the standards. Also, the constant checking of the actual costs against the standard costs brings many items to the attention of the management that might otherwise remain



standard costs in compilation of budget.

unnoticed. Furthermore, in many cases a system of standard costs is far more economical to use than the job-order plan.

Standard costs for direct labor can be determined accurately by time study. Standard material costs are easily obtained from the purchasing department or from material-cost records. Greater difficulty is involved, however, in setting up standards for factory expense. A combination of budget and standard cost plan is used effectively in some plants.

The following illustration[1] by G. Charter Harrison will be included here to give a definite picture of an actual installation of standard costs, even though it is a very simple one:

"In Diagrams I and II of Figs. 118 and 119 are illustrated the basic principles of a coordinated budget and standard cost plan which entirely eliminates the monthly distribution of burden to products. This is a system which can be successfully operated in that type of business where the product is rather uniform in character (as in the case of a manufacturer of gas engines used in the illustration) and where every department contributes to the manufacture of each item of product.

"Now while the plan illustrated in Diagram I is probably as simple and inexpensive as it is possible to devise any cost plan which merits the name, nevertheless the system will give information which cannot possibly be obtained under the usual cost methods despite their higher cost of operation. This information may be briefly summarized as follows:

Predetermined Costs and Profits.

"The cost summary and budget (Form A in the diagram) represents a complete forecast of costs, expenses, and profits for one year. It furnishes the chief executive with a detailed and definite objective for every division of the business—for the sales department, a detailed sales quota and a forecast of sales expenses by months; for the manufacturing department, a definite cost and production program; and for the administrative department, a detailed objective of expense. This cost summary and budget sets a definite objective of net profits for the year of $105,244.74 and illustrates clearly and unmistakably exactly what must be accomplished by each division of the business if this profit objective is to be realized.

"Before passing on, let us consider for a moment the simplicity of the cost summary and budget. The sales manager, on the basis of past experience and knowledge of current conditions, estimates what his sales will be of each type of gas engine per month. These estimated sales extended at the standard sales price give the estimated monthly sales volumes. The cost clerk

[1] HARRISON, G. CHARTER, Installating Standard Costs, *Mfg. Ind.*, vol. 13, No. 6, p. 425, June, 1927; vol. 14, No. 1, p. 23, July, 1927. For further discussion of standard costs see Mr. Harrison's recent book, "Standard Costs."

figures the standard labor and material cost of the engines to be sold and deducts these costs as also the estimated burden in total from the forecasted sales, leaving the forecasted gross profit for each month. From this gross-profit forecast are deducted the estimated administrative, financial, and distribution expenses, leaving the forecasted monthly net profits.

Profit Variation Analysis.

"Budgets and forecasts are of little practical value unless means are provided for keeping each executive, from the president down, posted at all times as to exactly where his accomplishment stands in relation to the objective set; and, if he has failed to realize these objectives, the reason why. The latter information is of supreme importance because unless he knows the causes of failure, the executive is likely to waste precious time going after the minor troubles instead of concentrating his attention on correcting the really serious ones.

"Under the plan which is being described, a daily report is furnished to the factory superintendent showing his actual labor costs in comparison with standard by departments and for the factory as a whole, variations being analyzed by causes. As stated in the previous article, this daily labor efficiency information enables the superintendent to check losses before they are permitted to reach large proportions, and furthermore acts as a stimulus to the foremen to exercise foresight and to guard against inefficiencies being permitted to occur.

"Of supreme importance to the chief executive is the complete monthly profit variation statement which compares the actual profits with the budget and then furnishes a complete analysis of the causes contributing to the variation. This report will show, for instance, how much the profits were decreased owing to failure to realize the sales quotas, and to cuts in prices. It will show also to what extent the profits were increased or decreased owing to fluctuations in the manufacturing costs, to selling a larger or smaller percentage of the more profitable items than provided for in the budget, and to variations from the standard administration, sales, and financial expenses.

"In this statement and in the daily labor efficiency statement profit losses are shown in red and profit gains in black."

Explanatory Notes Regarding Diagram I

Cost Summary and Budget (Form A)

Standard Sales Price

In this column is entered the regular selling prices of the various gas engines as existing at the time the budget is made. In the event that at the time of the budget compilation a change in price is contemplated, this change would of course be reflected in the budget figures.

Standard Cost per Engine. Material and Labor.

In these columns are entered the standard material and labor costs of each model of engine included in the sales quotas. The method of compiling these standard labor and material costs will be fully explained later.

Estimated Sales. Number and Value.

In these columns will be entered the estimated number of engines to be sold each month which extended at the standard sales price gives the estimated sales value.

Standard Cost. Material and Labor.

In these columns will be entered the standard material and labor costs of the estimated sales, this information being obtained by extending the forecasted sales of each model by the standard costs per engine, as, for instance, in the case of model 18 B in January where it is estimated that 35 engines would be sold. The standard material cost of this engine is shown as $73.20, so that the standard material cost of 35 engines is 35 × $73.20, or $2,562.00, as entered in the "Standard cost, material" column in January. Standard material and labor costs of repair parts are figured on a percentage basis, material being figured at 30 per cent of the estimated list sales of repair parts and labor as 11 per cent of list

Factory Burden.

The monthly factory burden estimates are posted to Form A from the standard burden schedule (Form B) as illustrated by line 5 on the diagram.

Administrative, Financial, and Distribution Expense.

The monthly estimates of these expenses are posted to Form A from the standard burden schedule as illustrated by line 6 on the diagram.

Standard Burden Schedule (Form B)

Weekly Pay Days in Month.

It is assumed in the illustration that weekly payrolls are made up to Saturday of each week and in this column is entered the number of Saturdays in each month. This information is used in figuring the expenses listed in

the column headed "Standard factory burden, expenses paid weekly," as illustrated by line 3, these weekly expenses being detailed in Form D.

Estimated Production. Sales Value.

In order to be able to apportion expenses varying with production by months on the budget, it is necessary to figure the approximate sales value of the production by months.

Monthly Fixed Charges.

In this column are entered those factory expenses which are in the nature of fixed monthly charges such as the salary of the foremen paid on a monthly basis, depreciation, and real estate and personal property taxes. The method of compiling these data is illustrated on Form C.

Expenses Paid Weekly.

In this column is entered the forecasted weekly factory salary payroll as made up on Form D.

Expenses Varying with Production.

In this column is entered the estimated cost of expenses which tend to vary directly with the production. The following is the schedule which is used in the illustration:

Estimated Annual Expense for Production of Sales Value of $1,000,000

Spoiled work	$ 4,350.00
Reclamation expense	6,000.00
Supplies	20,000.00
Electric power and light	6,500.00
Overtime allowance	750.00
Maintenance of equipment	2,300.00
Maintenance of tools	4,500.00
Etc.	Etc.
Total	$64,160.00

The above estimate represents 6.416 per cent of the estimated sales value of the production of $1,000,000 and is distributed by months in accordance with the figures in the "Estimated production, sales value" column, as for instance, in January where the estimated value of the production is $90,000 and accordingly the estimated charge for the month is $5,774.40.

Office Administration and General Expense.

It is assumed that expenses coming under this head are in the nature of monthly fixed charges. The illustrative schedule used in compiling the figures in this column is as follows:

	Estimated cost per month
Salaries, executive	$1,475.00
Salaries, clerks	661.50
Stationery and supplies	260.00
Postage	196.50
Telegraph and telephone	136.00
Collection expense	64.50
Professional services, audit, etc	340.00
General office expenses	214.75
Depreciation, office furniture	240.00
Other expenses, totaling to	731.75
Total	$4,320.00

Distribution Expenses.

These expenses are divided between those which are in the nature of fixed monthly charges and those which vary directly with the volume of sales. The latter are charged to the months in proportion to the sales quotas, as listed in the column headed Estimated Sales. The illustrative schedules used in compiling the figures shown in the diagram are as follows:

Distribution Expenses. Fixed Charge per Month

	Estimated expense per month
Traveling expense	$ 640.00
Advertising	3,000.00
Other expenses totaling to	700.00
Total cost per month	$4,340.00

Distribution Expenses, Varying with Sales

	Estimated expense for sales volume of $1,014,925
Commissions	$50,746.25
Shipping labor	6,480.00
Shipping supplies	4,824.00
Freight and express, outward	492.00
Other expenses totaling	13,714.27
Total per year	$76,256.52

Total per dollar of sales $0.07513512

Financial Expenses.

These forecasted expenses are also divided as between those which are in the nature of fixed charges per month and those expenses which tend to vary with the sales, the former including such items as bond interest and the latter, discounts allowed to customers.

Explanatory Notes Regarding Diagram II

Assembly Specification (Form E)

In order to be able to figure the standard cost of the cylinder assembly on Form I, it is necessary to have the specifications of the parts used in the assembly. This information is given on Form E, which is the engineering department's record. Line 7 illustrates the posting of the part numbers of the parts used in the assembly, the number of pieces of each part used and the number of the operation at the point where the part goes into the assembly. Details of the assembling operations are shown on the back of Form I as illustrated.

Standard Cost of Parts (Form F)

On this form is illustrated the figuring of the standard cost of the cylinder. The numbers and names of the necessary operations on this cylinder, and also the set-up rates and the piece-rates, are obtained from Form G, as illustrated by line 8.

Day-work costs are entered in green ink and are obtained by estimating the time required for the performance of the operation and extending this at the standard rate per hour for that class of work. Line 9 illustrates the method of recording a day-work cost.

It will be noted that provision is made in the upper left-hand corner of Form F for noting the standard number of pieces per set-up. In the illustration this is given as being 50. The standard costs being figured on the basis of 100 parts, it is necessary, in figuring the standard set-up cost of 100 cylinders, to take twice the set-up rate, which is done in the column "Set-Up Cost, Per 100."

The lower left-hand section of Form F is used for figuring the standard material costs. These costs represent a standard quantity extended at a standard price. In this case 100 castings is the standard quantity. The standard price of these castings is $18 each, which for 100 castings, therefore, totals $1,800.

It will be noted that provision is made for recording the material class, which for castings is Class C. The complete classification for materials is given on Form I, this being as follows:

Class A................	Brass	Class E..........	Purchased parts
Class B................	Steel	Class F..........	Stampings
Class C................	Castings	Class G..........	Miscellaneous
Class D................	Forgings		

Standard material prices should be the market or cost prices at substantially the same date. The method usually followed is to take as standard the prices of the inventory at the commencement of the year in which the standard cost system is introduced. If any item is figured in the inventory at a price entirely out of line with the market price at that date, this price should not be used as standard, but the market price should be used instead. All standard prices should be figured on an f. o. b. basis at the consumer's factory.

The section on the lower right-hand corner of Form F is used for analyzing the standard labor costs (as listed in the upper section of the form) by departments.

Standard Operation and Piece-work Rate Record (Form G)

This is the shop record and one of its uses is as a piece-work record in connection with figuring the operator's piece-work earnings. No change should be permitted to be made in any of the information on this card without having the changes also made on the standard cost sheet (Form F) It will be noted that provision is made on the latter form for recording changes so that the standard cost sheets at all times reflect the latest rates and routing.

Standard Operation and Piece-work Rate Record (Form H)

Identical with Form G.

Standard Cost Per 100 Assemblies (Form I)

Both the front and back of this form are illustrated. The front of the form is used for assembling the standard material and labor costs of the various parts used in the assembly, as illustrated by line 11. The standard assembling cost is detailed on the back of the form and posted in total to the front as illustrated by line 14.

Assembly Specification (Form J)

Form J is identical with Form E and lists the various parts and subassemblies required for the complete engine assembly.

Standard Operation and Piece-work Rate Record (Form K)

Form K is identical with Forms G and H and lists the operations and piece-rates for the assembling of the complete engine.

Standard Cost Per 100 Assemblies (Form L)

Form L is identical with Form I and represents the complete analytical standard labor and material cost of the 8-cylinder, 36 hp. engine. Line 15 illustrates the posting of the standard labor and material costs of the cylinder assembly from Form I. On the back of Form L are listed the details of the standard cost of the assembling operations, as shown in total on the front of Form L and as illustrated by line 18.

It will be seen that the totals of the columns of Form L furnish an analysis of the standard cost of the 8-cylinder engine by material classes and for labor by departments. These are the figures which were used in Diagram I as a basis for figuring the standard material and labor costs of the forecasted sales, as illustrated by line 19 on Diagram II and line 1 on Diagram I.

When the relative amount of labor in the different departments is about the same for all the products manufactured, the complications of applying overhead on a departmental basis can be avoided and one overall rate used. In the business which was taken as a basis for the illustration, when the

system was first installed burden was applied to the standard costs of individual engines on a departmental basis. Experience showed, however, that the difference in cost under this method, as compared with the costs when figured on a rate for the factory as a whole, was so trifling as not to justify the use of departmental rates.

The total standard cost of engine 36 F can be obtained by adding the burden as shown on Form A of Diagram I to the standard labor and material costs as detailed on Form L on Diagram II as follows:

Standard material cost per engine		$161.34
Standard labor cost per engine		76.92
Burden:		
Total for year, per Form A	$182,340.28	
Total standard labor cost of sales for year, per Form A	$175,432.94	
Per cent of standard labor		

$$\frac{182,340.28}{175,342.94} \text{ equals } 103.94 \text{ per cent.}$$

103.94 per cent of $76.92 equals	79.95
Total standard cost of engine	$318.21

PROBLEMS

Chapter I

1. Select the type of factory building to be used for the manufacture of flywheel clutches (see Appendix A). This problem will have to be worked out in connection with Prob. 7. Give a complete analysis of the problem showing why the particular type of factory building was chosen. A local site may be assumed for the location of the factory building.

2. Select the type of construction to be used for the flywheel-clutch factory building. What are the factors influencing the choice of the type of construction for industrial buildings? Evaluate these factors as they affect this particular problem.

Chapter II

3. Is the equipment listed in Appendix A the best that can be obtained to manufacture the flywheel clutch and give the greatest economy? Recommend at least two machines that might be used to replace present equipment and show in each case the number of years required for the new machines to pay for themselves at the present rate of output.

4. One Cleveland automatic screw machine (machine class A8) was installed to replace four hand-operated screw machines. The book value of the old hand-screw machines when scrapped was $200.00 each. The old piece rate was $1.35 per 100 pieces on operations 1 of parts C107 and C108; the piece rate on the new Cleveland Automatic is $0.25 per 100. Assuming the new machine to be depreciated to zero in 5 years, the interest rate at 6 per cent, and with a saving in operating cost of $450.00 per year, find the number of years in which the new Cleveland automatic screw machine will pay for itself at the present rate of output; consider parts C107 and C108 only.

5. Determine the economic lot size for a manufactured part using the following data:

a. Number of pieces required per month of 200 working days = 2,000
b. Capacity of equipment which produces this part, if operated on this job for the entire 200 working hours = 6,000
c. Rate of interest = 6 per cent
d. Total set-up and preparation cost = $30.00
e. Raw-material cost of the part = $3.85
f. Total cost of the finished piece = $7.50
g. The parts are used in equal quantities for assembly each day.
h. Neglect storage costs, depreciation costs, and breakage costs due to storage.

6. Using the data and drawings given in Appendix A, determine the amount of equipment needed to manufacture 4,000 flywheel clutches, with flywheel, crankshaft, and timing gear, per month of 200 working hr. (25 working days, 8 hr. each, per month). Assume the shop to operate at an efficiency of 90 per cent. The clutch will be assembled and crated ready for shipment. Benches are to be provided for the assembly of the clutch as well as for the subassemblies of the parts. The heat treating, hardening, and annealing will be omitted from this problem. Forges will be provided for in the calculations. Use a form similar to that shown in Fig. 19 for tabulating the data for this problem.

Sample Calculation.

Part C101 is the spacer for the clutch hub and there is one required per clutch, so that it is necessary to make 4,000 of these hub spacers per month. If ½ month's supply is machined at one set-up, it is possible to calculate the time that the various machines will be used in processing this particular part. The operation sheet for part C101 is shown in Appendix "A." The first operation on this part is to "drill and ream" on "heavy-duty drill" machine class D10. It requires 0.500 hr. to set up the machine and 0.038 hr. to drill each piece. The total time that the machine will be used on the drilling operation in making 1 month's supply of hub spacers will be

$$(4{,}000 \times 0.038) + (2 \times 0.500) = 152 + 1 = 153 \text{ hr.}$$

It requires 152 hr. to drill the pieces and 1 hr. to set up the machine twice; only ½ month's supply of hub spacers are machined at one set-up. This total time (153 hr.) is now placed on the form in Fig. 19, opposite the part name in the space under the name of the machine (machine class D10). The next operation is calculated in a similar manner. This operation is "Turn the outside diameter and straddle face to length." It is done on a 17-in. Le Blond engine lathe, machine class L38. The time needed is

$$(4{,}000 \times 0.050) + (2 \times 0.500) = 201 \text{ hr.}$$

and the same amount of time is required for the third operation which is done on the same machine. Therefore, 402 hr. are required of this machine on part C101. In a similar manner, the calculations are made for all of the operations on all of the parts and the results are recorded on the chart.

If the vertical columns of Fig. 19 are totaled, this sum will be the number of hours that the particular machine will be used in a month, or in making a month's supply of clutches. In the case of the heavy-duty drill (machine class D10), 319 hr. work will be done on this machine. If the month consists of twenty-five 8-hr. working days, then a single machine will be in operation 200 hr. It is unlikely that the machine would operate at 100 per cent efficiency all month, so an allowance must be made. In this case, 90 per cent will be used. Therefore, instead of doing 200 hr. work in a month, this drill will do only 180 hr. work ($200 \times 0.90 = 180$). By dividing the work to be done by the drill press (machine class D10) by the number of hours that the machine will operate per month, the quotient will be the number of machines required in the clutch factory. That is:

$$319 \text{ hr.} \div 180 = 1.77 \text{ machines.}$$

Since one machine does not have sufficient capacity to do all of the work, it is necessary to place two of the heavy-duty drills in the factory, although 1.77 would take care of the work. In a like manner, the number of machines is determined for each of the different machine classes.

Chapter III

7. Lay out the equipment that will be needed to manufacture 4,000 flywheel clutches per month, using a multistory reinforced concrete building. Provide for service centers, internal transportation, railroad sidings; and give proper consideration to all fundamentals of good layout, lighting, heating, and ventilation. Balance the departments and make provision for future expansion. Comply with all state laws and well-known industrial codes. Satisfy present practice with respect to safety and fire prevention. Use data in Appendix A.

Suggested Steps in Making the Plant Layout.

1. From the data given, estimate the approximate area of floor space that will be required for productive work. In making this estimate allow working space, temporary material storage space at each machine (see Fig. 25) where needed, aisle space, etc.
2. Sketch the general plan of the layout roughly to scale on 8½- by 11-inch cross-section paper. If a multistory building is used, make a plan for each floor showing elevators, stairways, and fire escapes. If the building is a reinforced concrete, multistory factory building, columns may be placed 20 ft. center to center, diameter of columns on the first floor 2 ft.; on the second, third, and fourth floors, 1½ ft. Exterior columns 2 ft. thick, curtain walls 8 in. thick, outside walls 12 in. thick, and the ceiling heights 16 ft.
3. Draw to scale (⅛ in. = 1 ft.) the machines that will be required for manufacturing the flywheel clutch. Cut out the templets and arrange them on the drawing board, giving proper consideration to the position of the operator, drive pulley, position of shafting, provision for the material and tools needed near the machine, etc. Locate the various departments, offices, cafeteria, tool cribs, locker rooms, and provide for all other necessary space.

Data for the Plant Layout.

1. Location of machines.
   a. Machines must not be placed so closely together as to be a serious menace to those who have to pass between them. Passageways must be of ample width, have sufficient head room, and be kept well lighted and free from obstructions.
   b. Assume machines to be driven through line shafts and countershafts unless otherwise noted.
   c. Allow 1 to 1½ ft. around each machine, between machine and walls, and between machine and the next unit unless there are good reasons to vary this.

d. Use machine data on page 326 to find correct "facing" of machines.
e. Bench size is 2 ft. 6 in. wide and 5 ft. long.

2. Receiving department.
   a. Location, first floor.
   b. Should have access to railroad siding and to the street for motor trucks.
   c. Floor space required, assume 500 sq. ft. per 1,000 clutches to be manufactured per month.
3. Shipping department.
   a. Location, first floor near the receiving department; in some cases may be combined with it.
   b. Allow 1,000 sq. ft. for lumber storage.
   c. Allow space for woodworking machines to be used in making up the crating lumber: rip saw 3½ by 4½ ft.; swing saw 2½ by 25 ft.; planer 6 by 16 ft.; jointer 3½ by 6 ft.; and band saw 4 by 5 ft. The lumber will come in 8- to 20-ft. lengths, and room must be allowed for handling.
   d. Allow further space for storing a few clutches which are crated ready for shipment. Space may be allowed for three car loads of clutches. A box car is 9 by 10 by 42 ft.
4. Finished stores.
   a. Location, first floor or another floor near the elevator close to the shipping department.
   b. Size, allow 300 sq. ft. per 1,000 clutches to be made per month.
5. Assembly.
   a. Assume that one man can assemble two clutches per hour.
   b. Each man will require an assembly bench 2 ft. 6 in. wide and 5 ft. long. Provide space for tote boxes and skid platforms.
6. Service centers on each floor.
   a. Foreman's office and time clerk, room for two desks, filing cabinet, and lockers.
   b. Tool crib in a convenient position with respect to the department that it serves.
   c. Wash and locker rooms.
7. Raw-material storage.
   a. Location, lower floors because of weight of material, close to receiving department.
   b. Bulk stores such as coal, iron, lumber, and sand in yards.
8. General offices.
   a. Location, apart from the manufacturing departments.
   b. Offices for sales, purchasing, finance, administration, employment, safety, etc.
   c. Engineering offices; planning, time study, and methods department offices central with respect to the building.
9. First-aid room and hospital.
   a. Location, central.
   b. Size, one or two rooms about 10 by 20 ft.
10. Tool-manufacturing department.
    a. Location, very often adjacent to, or with, the main tool room.

b. Will contain the ordinary machine tools required for tool making. Allow 1,200 sq. ft.

11. Cafeteria.
   a. Location, central and convenient for all employees.
   b. Size, dining room requires 15 sq. ft. per seat. Allow an additional 25 per cent for kitchen, storage space, and serving counters. One-half of the employees will be served.
12. Number of occupants.
   a. It will be assumed that the number of persons working on a floor will be 125 per cent of the number of machines on that floor. This number includes factory clerks and supervision.

8. Assuming that the machines have been arranged according to kind, that is, a department for each type of machine, trace by means of a red line the route followed by the "transmission-shaft" part C113 (Appendix A) from the time it leaves the storeroom until it is finished and assembled.

9. Instead of arranging the machines according to kind, lay out a department for the manufacture of the crankshaft (part S126), arranging the machines according to the sequence of the operations to be performed. Draw in a heavy line showing the general flow of work in this department. Use data in Appendix A.

10. Draw to scale ($\frac{1}{32}$ in. = 1 ft.) proposed plan for expanding the present plant to twice its size. Show in full lines the present buildings and, in dotted lines the additions to be made. Show changes, if any, in railroad sidings, motor-truck drives, material-storage yards, and the rearrangements of the departments within the present plant that will take place when additions to the plant are made.

Chapter IV

11. Select the materials-handling equipment to be used in the flywheel-clutch factory. Outline in detail the kind and amount of equipment that will be used for handling each part manufactured. Would a single-story building make the materials-handling problem easier or more difficult? Explain.

12. If the crankshaft (part S126) is to be manufactured as explained in Prob. 9, what kind of materials-handling equipment would be used in this department? What provision would be made for lifting the crankshaft into the machines and removing it in each case?

13. Would it be economical to use a conveyor in the assembly department of the flywheel-clutch factory? Determine the size and kind that might be used. Collect cost data for the installation and operation of such a conveyor.

Chapters V and VI

14. Find the height of the windows that should be used in the side walls of a single-story building (no skylights) to give a minimum intensity of illumination of 12 ft.-candles in the center of the building. The width of the building is 80 ft. Assume an overcast sky and dirty windows.

Plot a curve showing the intensity of illumination at 5-ft. intervals from the windows to the center of the building.

15. Solve the above problem using a monitor-type single-story building. Assume the total width of this building to be 120 ft.

16. Provide general artificial lighting for the flywheel clutch factory. Make a layout to scale showing the location of the outlets, position of the interior and exterior columns, and indicate positions of the skylights if such are used.

Data.

Intensity of illumination required = 10 ft.-candles.
Reflectors to be used, R.L.M.
Interior walls and ceilings painted "mill" white.
Plane of work 2½ ft. above the floor.
Mazda C-filament lamps to be used at 110 to 125 volts.
Depreciation factor, 0.70.

Chapters VII and VIII

17. Make a stop-watch time study in the shop of:
a. Drilling a small piece in a jig on a single-spindle sensitive drill.
b. Turning a small piece in a lathe.
c. Milling a cast-iron piece in a fixture or strapped to the table.
d. Machining a simple piece in an automatic screw machine. After the study is made, find the base time by the (1) "modal" method, (2) "average" method. Add 10 per cent for allowances. Make instruction cards where necessary.

18. Make rate tables for setting standard time for typewriting letters, addressing envelopes, etc.

19. Calculate the standard time for turning (operation 5TR) the change gear (part 1075AP shown on page 137, if the diameter is 6.45 instead of 7.700 in. Face is 1.250 instead of 1.000 in. Use the time-setting tables and charts given.

20. Determine the standard time for drilling part S135 (shown on page 130) if the piece is 1.525 in. in diameter and the actual drilling time is 0.69 min. Use time-setting tables for sensitive drills.

21. What objections might be made against stop-watch time study as it is used in industry today? What parts of the time study are affected most by the judgment of the time-study observer? Enumerate all possible objections and evaluate each.

22. After the stop-watch time study has been made in Prob. 17 *a*, make a complete set of suggestions as to the changes in the work place that could be made to facilitate the performance of the work. Show what elements or motions might be eliminated and where improvements in sequence might be effected.

Chapter IX

23. Select some one of the well-known plans of wage payment that would be suited to the needs of the flywheel-clutch factory. Give in detail reasons for the selection. If some modifications are desired, explain the changes that should be made and why.

24. Design a plan of wage payment that will combine both quality and quantity features. The incentive will be based upon both of these two factors. Adapt this plan for use in the crankshaft department of the flywheel clutch factory.

25. A manufacturer wishes to set time standards on all operations in his plant. The employees are paid on a time basis and wage incentives have never been used. Design a plan for calculating and using labor efficiencies in this plant, and give in detail the merits and disadvantages of such a plan.

Chapter X

26. Make a careful study of all factors that influence the base rates in the local community and then determine the index or weight that should be given to each of these factors in order to arrive at a just base wage. Make the plan applicable for all occupations or jobs in the clutch factory.

27. Design a job-specification form that can be used effectively in analyzing the different jobs or occupations that would be found in the flywheel clutch factory.

28. Explain in detail how the base rates of an industrial plant might be increased or lowered with least trouble to the management and to the satisfaction of all employees. Under what conditions would a manufacturer want to lower the base rates?

Chapters XI and XII

29. Design some plan for determining the productive and the nonproductive ratios for the labor in the factory manufacturing the flywheel clutches. Show how the plan will aid in the determination of standard labor costs.

30. Work out an incentive plan of wage payment for the nonproductive employees in the factory. Show how the plan will affect the quality of the work done, the cost of manufacturing, and the control of the work in the factory.

31. How is it possible to justify the use of a 75 per cent premium for all production above a 60-point hour? How is any system of wage payment justified where the worker is paid less than the equivalent of a straight piece rate? Give the major factors involved and evaluate each.

32. What advantages result from the combination of labor efficiency and cost efficiency into one index number such as the "supervision point hour"?

33. Consider the merits of expressing the equivalent of the "supervision point hour" in dollars and cents instead of "points."

34. What modifications might be made in the "point system" as it is explained in this chapter to reduce the clerical work involved in making up the pay roll, analysis sheet, and posting sheet?

35. Determine the "supervision point hour" as explained on the analysis sheet in Fig. 105, using the following data:

Name of company: The American Motor Company,

Date: Aug. 15, 1930.

Department: 23.

Clock hours worked by direct and indirect labor in the department, as taken from the time cards for that day: 243.65 hr.

Departmental time summary sheet:

Summary of labor ticket for Aug. 15, 1930, for analysis sheet:

Points from production at 60 = 200

Points for allowances:

Machine breakdown	= 0	
Wait for work	= 30	
Power off	= 0	
Time in hospital	= 30	
Total	=	60

Minutes (points) for indirect labor:

Supervision	= 600	
Clerical	= 750	
Handling	= 1,390	
Maintenance	= 150	
Set-up	= 525	
Inspection	= 375	
Janitor	= 465	
Total	=	4,255

Total of production at 60, allowance and indirect minutes (points) = 4,515

. . . . . .

Total direct and indirect points produced for the day	= 18,050
Production at 60, allowances and indirect minutes (points)	= 4,515
Direct points	= 13,535

. . . .

Total indirect-labor points (minute) = 4,255

∴ 4,255 ÷ 60 = 70.9 total indirect hours

Janitor work = 465 min.

∴ 465 ÷ 60 = 7.75 hr.

70.9 − 7.75 = 63.15 net indirect hours

. . . .

Total pay roll on Aug. 15, 1930, for:

Supervision	= $8.00
Clerical	= 6.84
Handling	= 11.60
Maintenance	= 1.25
Set-up	= 3.86
Inspection	= 4.08
Janitor	= 3.72
Total indirect labor cost	$39.35

. . . .

Deduct for spoiled work 150 points from inspection department.

Total pay roll for direct and indirect labor = $135.12.

Total premiums for direct labor = $ 12.10

Chapter XIII

36. Determine the machine-hour rate for each of the machines used in the manufacture of the flywheel clutch. Take the actual data from the layout of the factory as required for Prob. 7. Use the straight-line method for calculating the depreciation of equipment. Use a form similar to that shown in Fig. 117 for tabulating the data.

37. Find the total factory cost of manufacturing the flywheel clutch. Distribute the factory expense by using the machine-hour rates as determined in the previous problem.

38. Design time cards and pay-roll forms to be used by the flywheel clutch factory and develop a complete system for charging direct-labor costs to particular orders.

39. Design stores issues and any other forms that will be needed in accounting for direct-material charges.

40. Could standard costs be used in industries with considerable seasonal fluctuations in output? Design a system of standard costs that might be applied to such an industry. (For reference see F. F. Hovey and C. E. K. Mees, Cost Control for Fluctuating Production, *Bull. Taylor Soc.*, vol. **14**, No. 4, p. 160, August, 1929.)

APPENDICES

APPENDIX A

GENERAL STATEMENT OF THE PROBLEM

The American Motor Company,[1] now operating in the eastern part of the United States, manufactures automobile motors, transmissions, and differentials which are sold to different customers throughout the country. The products are manufactured to customers' orders, drawings, and specifications. The orders are usually received for large quantities and the assemblies are shipped in about equal monthly amounts. These assemblies are used in the manufacture of nationally advertised automobiles, trucks, cabs, and tractors. The company plans to build a plant to manufacture all the clutches, crankshafts, and flywheels needed. With the exception of these parts, the motor is built elsewhere. The requirements of this plant are that it shall be capable of producing 4,000 finished crankshafts, flywheels, and clutches per month of 25 working days of 8 hr. each. The clutches are to be assembled and crated ready for shipment.

The exact design of the parts will vary with the different customers' orders, but for the purpose of the problem of determining the size and layout of the factory, a typical set of drawings and manufacturing data can be used. Because the product will vary slightly with the different customers' orders it becomes impossible to manufacture by the continuous method and it is likely that units for several different customers will be in the process of manufacture at the same time.

Description of the Clutch.

The flywheel clutch is designed to be mounted in the same housing as the transmission, so the pedal and connecting links are made and assembled with the transmission. The clutch is of the double-disk dry-friction type, and the complete assembly is shown in Fig. 120. The one main disk, which is called the "drive plate" (part C114), is connected to the flywheel, and the two pressure plates on either side of this plate give the clutch-

[1] A fictitious name.

ing action. The flywheel, timing gear, and crankshaft are all made as separate units and finally will be assembled along with the clutch, transmission, and other parts to form the motor and transmission unit.

The detailed parts of the clutch which are to be manufactured are shown in Fig. 121. The name and number of each part

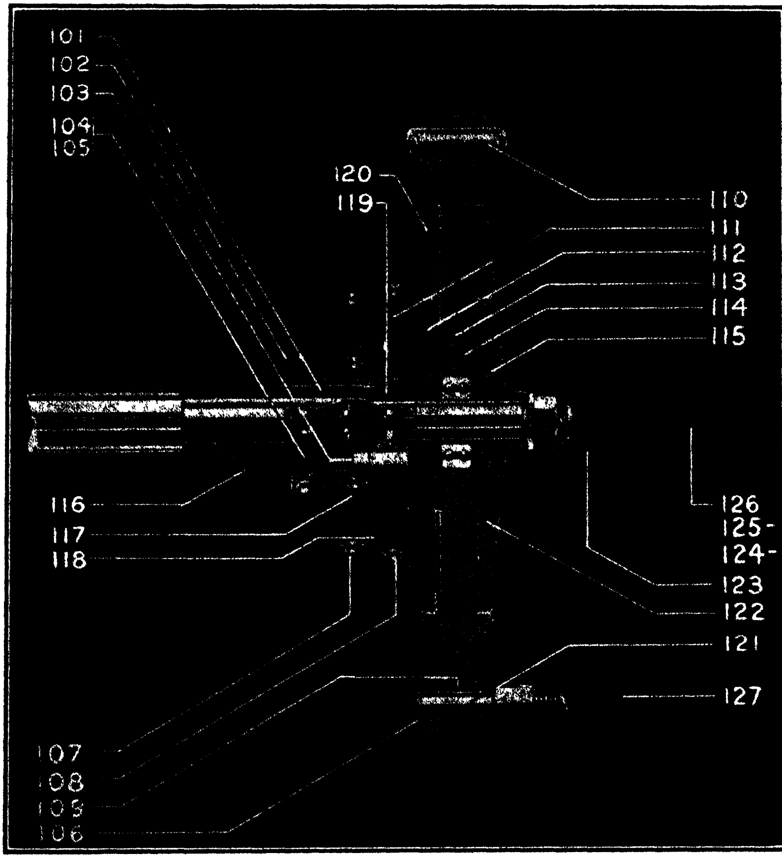


FIG. 120.—Flywheel-clutch assembly.

of the clutch are indicated on page 293. The details of the flywheel, timing gear, and crankshaft are shown in Figs. 122 and 123. Operation sheets and all machine data are given on the following pages.

Parts which are more easily and cheaply purchased in quantities are listed at the bottom of page 293, but no operation sheets

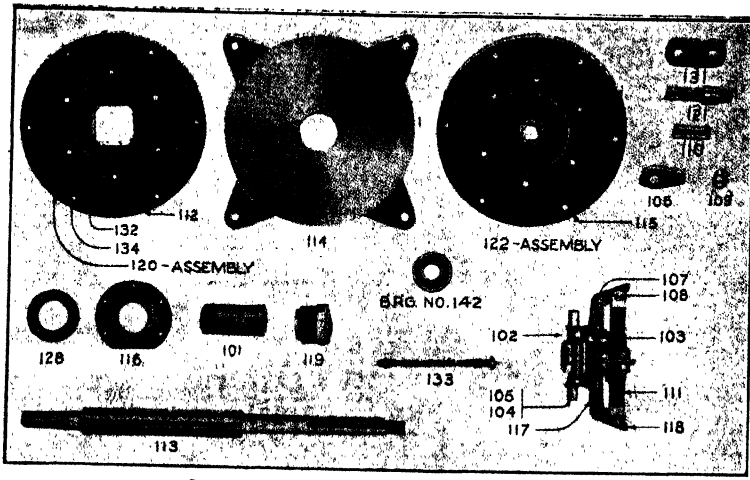


Fig. 121.—Parts of the flywheel clutch.

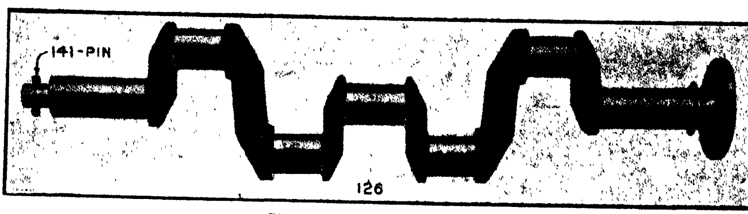


Fig. 122.—Crankshaft.

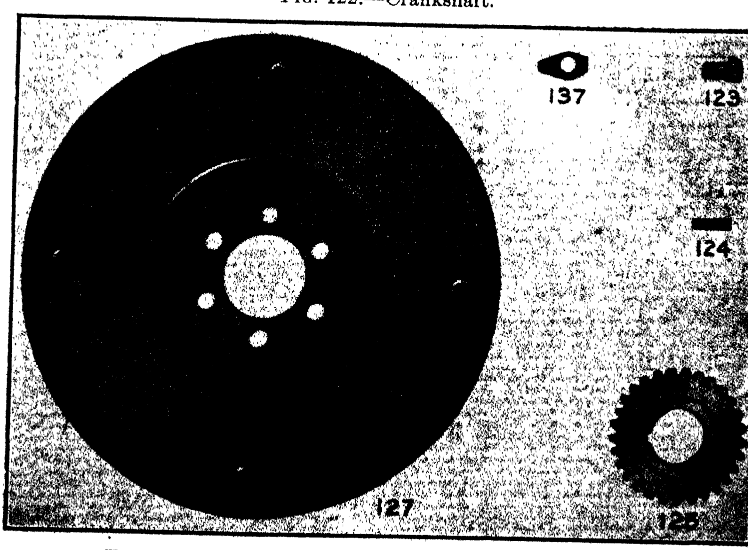


Fig. 123.—Flywheel, timing gear, and parts for assembly.

are shown for these parts. Most of these parts are standard and could be readily obtained in almost any quantity desired.

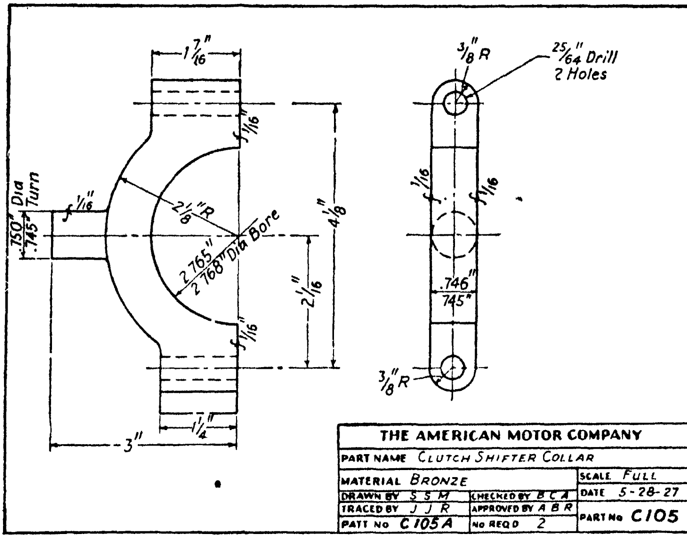


FIG. 124.—A detailed drawing of one of the parts used in the flywheel clutch.

Product Analysis.

Suppose the sales department receives an order for 24,000 automobile clutches to be delivered at the rate of 1,000 per week.

OPERATION SHEET — PART No. C 105

PART NAME Clutch Shifter Collar — CUSTOMER Eastern Motor Co. — ORDER No

METHODS 1-28-27 R.R.J. — TIME STUDY 1-31-27 B K M — QUANTITY

OPER	NAME OF OPERATION	TOOL NO.	NAME OF TOOLS	DEPT.	MACH CLASS	SPEED R P M	FEED	No CUTS	No. PER CHUCKING	STD TIME SET UP	STD TIME PER PC
1.	Mill Lugs			M42	M1	170	18 32	1	1	750	.008
2	Drill Bolt Holes			D37	D13	1080	0059			300	009
3	Spotface Drilled Holes			D37	D10	426	Hand			.300	004

FIG. 125.—This operation sheet shows the method of machining the clutch-shifter collar shown in Fig. 124.

It is desirable to know the exact procedure that will be used in placing the order in the shop. The following is typical of that used in many factories. When the order is placed for the

clutches, it would necessarily be accompanied by (1) the assembly drawing, (2) the detailed drawings for each part (as in Fig. 124) and (3) the material-specification sheet (similar to Fig. 129). In some cases the purchaser will send operation sheets indicating the methods of manufacture, heat treating, etc.

Engineering Department.

If, however, it is necessary to design the clutch for the customer, this will be done by the engineering department, and the drawings and specifications will then be made by this department. The engineering department should always work in close coopera-

INSTRUCTION SHEET

Customer *Eastern Motor Co*
Part No *C 105*
Op No *1 ML*

Part Name *Clutch Shifter Collar*
Operation Name *Mill Lugs*
Dept. *M42* Mach Class *M1* Mach Name *Automatic Horizontal Mill*
Made by *J J R* Approved by *V S K* Date *Jan 6 '27* Mat'l. *Bronze Cast*

No	Operations	Tools-Jigs Etc	Speed Setting	Speed Ft/Min	Feed Setting	Feed In/Rev	Base Time
1	Place piece in fixture						04
2	Place clamp and tighten nut						09
3	Table up and start						03
4	MILL LUG–Travel 1 1/2	Cutter 4" diam	170	RPM		18 32	08
5	Table up between lugs						03
6	MILL LUG–Travel 1 1/2		170	RPM		18 32	08
7	Table back						
8	Release nut and remove clamp (during operation No 7)						07
9	Remove piece from fixture and place in tote box						.03
		Base time					.45
		Allowance	15%				07
		Standard time per piece					52
		Standard time per piece in hrs					.009
		Set up time = 45 00 min = 0.750 hrs					

FIG. 126.—Instruction sheet for operation 1 ML on clutch-shifter collar, part C105.

tion with the production department and it is often possible to reduce manufacturing costs considerably by making slight changes in design, or in the kind of material to be used.

Methods Department.

The detailed drawing of the part and the production order are sent to the methods department; and the operation sheet (as Fig. 125) is made up from the drawing. This sheet shows the operations to be performed in manufacturing the part. It gives the operation number, the machine class, the department number, and the tools to be used. It requires a thorough knowl-

INSTRUCTION SHEET

Customer *Eastern Motor Co*
Part No. *C 105*
Op No. *2 DR*

Part Name *Clutch Shifter Collar*
Operation Name *Drill Bolt Holes*
Dept *D 57* Mach Class *D 13* Mach. Name *Multiple Drill*
Made by *JSR.* Approved by *V S K* Date *Jan 6, 1927* Mat'l *Bronze Casting*

No.	Operations	Tools-Jigs, Etc	Speed Setting	Speed Ft/Min	Feed Setting	Feed In/Rev	Base Time	
1	*Place piece in fixture and set air*							.07
2	*Place head to work and start*							.06
3	*DRILL TWO HOLES $\frac{25}{64}$" - Travel $1\frac{9}{16}$*		1080	RPM		00059		.26
4	*Raise head*							.03
5	*Release air*							.02
6	*Remove piece from fixture and place in tote box*							.05
		Base time						.49
		Allowance	12%					.06
		Standard time per piece						.55
		Standard time per piece in hrs						.009
		Set-up time = 30 min =	0.500 hrs					

FIG. 127.—Instruction sheet for operation 2 DR on clutch-shifter collar, part C105.

INSTRUCTION SHEET

Customer *Eastern Motor Co.*
Part No. *C 105*
Op. No. *3 DR*

Part Name *Clutch Shifter Collar*
Operation Name *Spotface Drilled Holes*
Dept *D 57* Mach. Class *Class D10* Mach. Name *Foote-Burte Heavy Duty Drill*
Made by *JSR.* Approved by *V.S.K* Date *Jan. 15-'27* Mat'l *Bronze Casting*

No	Operations	Tools-Jigs, Etc	Speed Setting	Speed Ft/Min	Feed Setting	Feed In/Rev	Base Time	
1	*Place piece on table*							.05
2	*Lower spotface locate and start (2 x 0.02)*							.04
3	*SPOTFACE TWO HOLES (2 x 0.03)*	*$\frac{7}{8}$" Dia Spotface*	426	R.P.M.	Hand			.06
4	*Raise spotface (2 x 0.01)*							.02
5	*Move to next hole*							.02
6	*Place piece in tote box*							.03
		Base time						.22
		Allowance 5% to grind tools						.01
		Allowance 10%						.02
		Standard time per piece						.25
		Standard time per piece in hrs						.004
		Set-up time = 18.00 min. = 0.300 hrs.						

FIG. 128.—Instruction sheet for operation 3 DR on clutch-shifter collar, part C105.

PACKARD MOTOR CAR COMPANY
DETROIT, MICHIGAN
SPECIFICATION
for
CHROME NICKEL STEEL BARS AND BILLETS
(Hot Rolled)

Number 335
Date issued 9–15–26
Replaces issue of 12–9–24

CHEMICAL COMPOSITION:

1. The chemical composition shall conform to the following limits:

	C.	Mn.	P.	S.	Cr.	Ni.
Desired	0.35	0.60	.....	.....	0.80	3.00
Low	0.30	0.45	.....	.....	0.60	2.75
High	0.40	0.75	0.040	0.040	0.95	3.25

PHYSICAL PROPERTIES:

2. When heat-treated by normalizing, quenching, and drawing to a hardness of approximately 302 Brinell, the bars shall have the following minimum physical properties.
   Bars larger than 1 in. across shall be reduced by machining to 1 in. round before heat-treatment. The bar shall be taken approximately one-half the distance between center and outside.
   Elastic limit, lbs. per sq. in. 125,000
   Tensile strength, lbs. per sq. in. 140,000
   Elongation, per cent in 2 in. 17.0
   Reduction of area, per cent. 55.0
3. The tensile bars shall be Packard standard bars. Blue prints for these bars may be had from the Packard Motor Car Company, Metallurgical Department.
4. The steel must be manufactured by the basic open-hearth or electric-furnace process. Acid open-hearth steel may be used if the Packard Motor Car Company, Metallurgical Department, is notified.
5. The bars shall be free from pipes and undue segregation.

FINISH:

6. The bars shall be sound, be free from laps, cracks, twists, seams, and other injurious defects, and have a workmanlike finish.

MARKINGS FOR IDENTIFICATION:

7. Bars conforming to this specification shall be painted white with a dark blue stripe on both ends. If bars are bundled, bars of one heat number only will be allowed in one bundle which must be properly labeled with heat number and mill number for identification. If bars are not bundled, the heat number must be stamped on each bar.

   Approved by *W. H. Graves.*

FIG. 129.—Typical specification sheet for materials. (*Courtesy of the Packard Motor Car Company.*)

edge of manufacturing methods and of shop equipment to be able to determine the best methods of manufacture.

Time-study Department.

After the methods department determines the machines to be used, it is then possible for the time-study department to set the time standards for setting up the machine and for performing each operation. If the same job has been done in the shops before, there will be time studies and instruction cards available as shown in Figs. 126, 127, and 128.

Planning Department.

The detailed drawing, the operation sheet, and the instruction cards are sent to the planning department where they are filed. The delivery date and the quantity to be manufactured are known for each part or assembly, and the length of time required to machine and assemble each part is shown by the operation sheet. Therefore, it is possible to plan ahead and estimate the time that each part should be started into the shop so that the finished clutch will be ready for delivery at the desired date.

List of Parts for Flywheel Clutch

Part number	Part name	Number per assembly
	Manufactured parts	
C101...	Spacer for clutch hub	1
C102...	Release collar for clutch	1
C103...	Pin for clutch-release collar	1
C104...	Clutch-shifter collar assembly	1
C105...	Clutch-shifter collar	2
C106...	Lock for clutch-drive pin	4
C107...	Pin for clutch-release link	8
C108...	Pin for clutch-release cam	4
C109...	Clutch-driving link spacer	4
C110...	Pin for clutch-drive link	4
C111...	Clutch-adjusting collar	1
C112...	Clutch-pressure plate	1
C113...	Transmission shaft	1
C114...	Clutch-driving plate	1
C115...	Clutch-driven plate	1
C116...	Front bearing retainer for transmission shaft	1
C117...	Clutch-release link	8
C118...	Clutch-release cam	4
C119...	Clutch hub	1
C120...	Pressure-plate assembly	1
C121...	Clutch drive pin	4
C122...	Driven-plate assembly	1
F123...	Flywheel bolt	6
S124....	Crankshaft-timing gear key	1
S125....	Crankshaft-timing gear	1
S126....	Crankshaft	1
F127...	Flywheel	1
	Purchased parts	
PC128...	Friction disk for clutch brake	1
PC129...	Washer for clutch-retainer nut	1
PC130...	Driving-pin washer	16
PC131...	Clutch-driving link (leather)	32
PC132...	Friction disk	2
PC133...	Shifter-collar grease tube	1
PC134...	Rivet for clutch disk	24
PC135...	S. A. E. bolt ½ in., 20 by 2¾ in. for C111	1
PC136...	S. A. E. bolt ⅜ in., 24 by 3¼ in. for C104	2
PF137...	Flywheel-bolt lock washer	6
PC138...	Crank-case rear-cover felt washer	1
PC139...	S. A. E. castle nut 1 in., 14 for C113	1
PC140...	Flathead machine screws 14, 20 by ½ in.	4
PS141....	Pin for starting crank	1
PC142...	Ball bearing for C114	1
PC143...	Cotter pin ⅛ by 1½ in. for C113	1
PC144...	Cotter pin ⅛ by ¾ in. for C107 and C108	24
PC145...	Cotter pin 5⁄16 by 1¼ in. for C110 and C121	12
PC146...	Grease cup, ⅛ in. No. 0 for C114	1
PC147...	Washer for driving link pins	12

Operation Sheets

Part name: spacer for clutch hub. Part C101
Material: gray iron casting.
Number pieces per assembly: 1.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Drill and ream.......	D10	Drill.........	0.500	0.038
2	Turn O.D. to size and straddle face to length	L38	Lathe........	0.500	0.050
3	Chamfer one end and chase thread	L38	Lathe........	0.500	0.050

Part name: release collar for clutch. Part C102
Material: Malleable iron casting.
Number pieces per assembly: 1.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Bore, ream, face, and break sharp corners from ear side	L21	J. & L.......	2.250	0.040
2	Face, turn, form groove, and break sharp corners	L2	Potter & Johnson	2.500	0.100
3	Drill driving pin hole	D16	Drill.........	0.333	0.020
4	Straddle mill ears....	M48	Mill..........	0.750	0.029
5	Drill, ream, and burr ears	D18	Drill.........	0.500	0.050

Part name: pin for clutch-release collar. Part C103
Material: ½ diam. C.F.S. S.A.E. 3135.
Number pieces per assembly: 1.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Round end and cut off	A4	Cone automatic	0.750	0.0004
2	Grind off burrs.......		Bench.......	.....	0.003
3	Cut threads.........	A5	Cleveland automatic	0.750	0.004

Operation Sheets

Part name: clutch-shifter collar assembly. **Part C104**
Material: assembly.
Number pieces per assembly: 1 each.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Assemble two collars No. C105 using two bolts, two ⅜-in., 24 hex nuts and two ⅜-in. lock washers	....	Bench.......	.....	0.030
2	Face both sides......	G30	Blanchard...	0.500	0.020
3	Bore, ream and chamfer	D15	Radial drill..	0.500	0.035
4	Turn trunnions......	D14	Drill.........	0.500	0.020
5	Drill, counterbore and tap one trunnion	D25	Tapping drill.	0.417	0.025
6	Cut oil groove.......	M45	Hand mill....	0.750	0.008

Part name: clutch-shifter collar. Part C105
Material: phosphor-bronze casting.
Number pieces per assembly: 2.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Mill lugs............	M1	Mill.........	0.750	0.009
2	Drill bolt holes.......	D13	Drill.........	0.500	0.009
3	Spotface drilled holes	D10	Drill.........	0.300	0.004

Part name: lock for clutch-drive pin. Part C106
Material: No. 14 Ga. (.078) B.A.S.S., sheets 24 by 96.
Number pieces per assembly: 4.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Shear stock to fit stripper	P53	Shears.......	.....	0.001
2	Punch hole and blank	P55	Punch press..	0.500	0.001

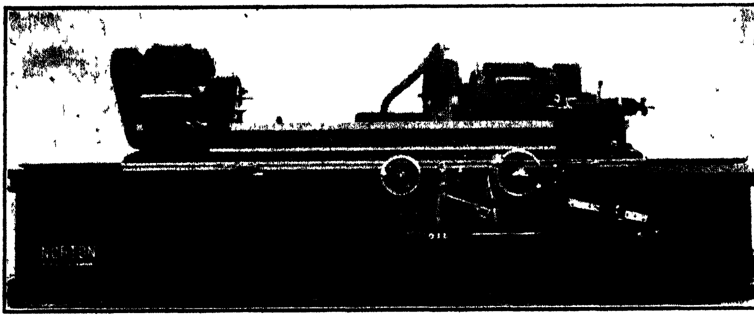
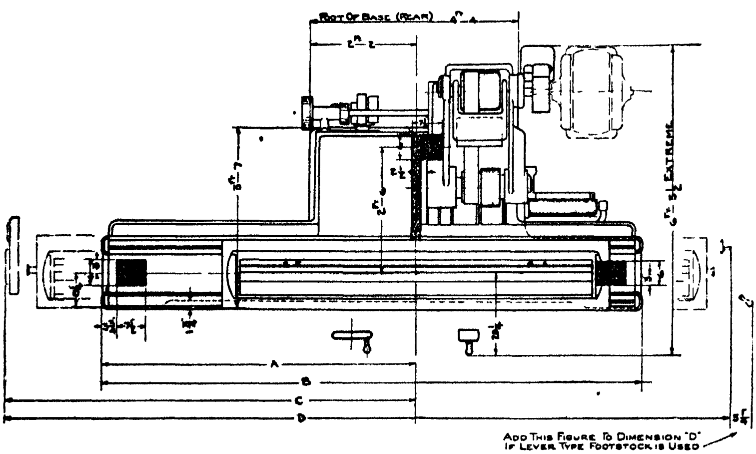


FIG. 130a.—Norton cylindrical grinder, 14 by 72 in. type A. Power traverse, machine arranged for motor drive, with motor-driven headstock. (*Courtesy of the Norton Company.*)



MOTOR-DRIVEN MACHINES WITH MOTOR-DRIVEN HEADSTOCK

Table of Dimensions

Size, in.	A	B	C	D
14 and 16 by 36	5 ft. 4¼ in.	9 ft. 2½ in.	6 ft. 7½ in.	11 ft. 8½ in.
14 and 16 by 50	6 ft. 5¾ in.	11 ft. ½ in.	7 ft. 9½ in.	14 ft. ½ in.
14 and 16 by 72	8 ft. 3¾ in.	13 ft. 11½ in.	9 ft. 7½ in.	17 ft. 8½ in.
14 and 16 by 96	10 ft. 3¾ in.	17 ft. 11½ in.	11 ft. 7½ in.	21 ft. 8½ in.
14 and 16 by 120	12 ft. 3¾ in.	21 ft. 11½ in.	13 ft. 7½ in.	25 ft. 8½ in.
14 and 16 by 144	14 ft. 3¾ in.	25 ft. 11½ in.	15 ft. 7½ in.	29 ft. 8½ in.

FIG. 130b.—Floor plans of type A 14 in. Norton cylindrical grinders.

Operation Sheets

Part name: pin for clutch-release link. Part C107
Material: ½ in. diameter C.F.S. S.A.E. 1020, permit 1120–1112 M.L.
Number pieces per assembly: 8.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Chamfer corners and cut off	A8	Cleveland automatic	2.000	0 004
2	Drill holes and burr .	D6	Five-spindle drill	0.750	0 002
3	Harden in cyanide and test		H.T.		

Part name: pin for clutch-release cam. Part C108
Material: ½ in. diameter C.F.S. S.A.E. 1020, permit 1120–1112 M.L.
Number pieces per assembly: 4.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Chamfer corners and cut off	A8	Cleveland automatic	2.000	0.004
2	Drill holes and burr. .	D6	Five-spindle drill	0.750	0.002
3	Harden in cyanide and test		H.T.		

Part name: clutch-drive link spacer. Part C109
Material: ¾-in. standard black pipe M.L.
Number pieces per assembly: 4.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Cut stock to length. . .	L42	Southworth screw machine	0.583	0.006
2	Remove burr from cut off tool	L35	Centering lathe	0.200	0.003

Operation Sheets

Part name: pin for clutch-drive link. Part C110
Material: ¾ in. diameter C.F.S. S.A.E. 1020 M.L., permit 1120–1112.
Number pieces per assembly: 4.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Round end and cut off to length	A4	Cone automatic	0.750	0.0005
2	Drill and burr holes...	D17	Sensitive drill	0.333	0.033

Part name: clutch-adjusting collar. Part C111
Material: malleable iron casting.
Number pieces per assembly: 1.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Bore, face, chamfer, and tap	L20	Warner and Swasey	1.750	0.083
2	Drill and burr driving-pin hole	D18	Sensitive drill	0.333	0.020
3	Straddle mill ears....	M50	Mill.........	1.000	0.067
4	Remill clamping ear and mill seats for clamp bolt	M50	Mill.........	0.750	0.019
5	Mill slot in clamp bolt ear	M50	Mill.........	0.750	0.033
6	Remove burrs........	....	Bench.......	.....	0.017
7	Drill and ream ears, drill clamp bolt hole	D15	Radial drill...	0.500	0.083
8	Burr all holes and tap driving-pin hole	D25	Tapping drill.	0.333	0.020

OPERATION SHEET

Part name: clutch-pressure plate. Part C112
Material: Gray iron casting.
Number pieces per assembly: 1.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Rough face	L39	Lathe	0.500	0.120
2	Grind opposite face	G30	Blanchard grinder	0.500	0.033
3	Broach	B34	Lapointe broach	0.400	0.020
4	Turn and finish face	L39	Lathe	0.500	0.100
5	Drill holes	D12	Multiple drill	1.000	0.006

OPERATION SHEET

Part name: transmission shaft. Part C113
Material: 2⅛ in. diameter. H.R. or C.F.S. S.A.E. 2345.
Number pieces per assembly: 1.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Saw stock to length..	S23	Newton circular saw	.....	0.050
2	Center drill both ends	L35	Centering lathe	0.250	0.041
3	Rough turn diameters on short end and largest spline diameter and cut relief	L43	Lo-swing lathe	0.750	0.250
4	Rough turn diameters on long end and cut relief	L43	Lo-swing lathe	0.500	0.184
5	Grind large spline diameter and bearing diameter on long end	G27	Norton grinder	0.500	0.133
6	Grind spline and bearing diameter on short end	G27	Norton grinder	0.500	0.100
7	Rough spline largest spline diameter	H31	Barber Colman	0.750	0.317
8	Finish spline largest spline diameter	H31	Barber Colman	1.083	0.328
9	Spline long end......	H31	Barber Colman	0.983	0.224
10	Spline short end.....	H31	Barber Colman	0.750	0.133
11	Chase thread on long end	L39	Lathe........	0.500	0.083
12	Chase thread on short end	L39	Lathe........	0.500	0.083
13	Drill and tap short end	D25	Tapping drill	0.400	0.055
14	Drill cotter pin hole in long end	D18	Drill.........	0.333	0.017
15	Remove burrs........	....	Bench.......	.....	0.017

Operation Sheets

Part name: clutch-driving plate. **Part C114**
Material: gray iron casting.
Number pieces per assembly: 1.

Operation number	Name of operation	Machine		Standard time, hour	
		Class	Name	Set-up	Per piece
1	Face one side, leave 0.015 in. for grinding, bore, ream, and chamfer hole	L39	Lathe..	0.750	0.200
2	Face 2d side, leave 0.015 in. stock for grinding and chamfer hole	L39	Lathe........	0.500	0.140
3	Grind both sides.....	G30	Blanchard grinder	0.500	0.066
4	Drill driving pin holes	D12	Drill.........	0.750	0.033
5	Ream driving pin holes	D10	Drill.........	0.333	0.033
6	Balance.............	D15	Radial drill...	0.333	0.085

Part name: clutch-driven plate. **Part C115**
Material: gray iron casting.
Number pieces per assembly: 1.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Turn flange.........	L19	Warner and Swasey	0.500	0.040
2	Face flange, bore and ream hole, face hub on both sides	L19	Warner and Swasey	2.000	0.150
3	Drill holes in flange...	D12	Drill.........	0.833	0.033
4	Broach splines.......	B33	Lapointe Broach	0.400	0.020

OPERATION SHEETS

Part name: front bearing retainer for transmission shaft. Part C116
Material: gray iron casting.
Number pieces per assembly: 1.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Turn, face flange and hub, bore, and ream hole and face opposite side	L22	Warner and Swasey	1.000	0.070
2	Drill all holes........	D13	Drill	0.783	0.021
3	Tap four holes.......	D25	Tapping drill	0.333	0.017
4	Mill flat on flange.. .	M1	Mill.........	0.750	0.009

Part name: clutch-release link. Part C117
Material: $^3/_{16}$ by $^7/_8$ in. wide C.F.S. M.L.
Number pieces per assembly: 8.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Cut radius and cut off to length	P52	Punch press..	0.750	0.003
2	Flatten.............	T32	Trip hammer.	0.500	0.001
3	Drill and ream holes..	D18	Drill.........	0.333	0.020
4	Burr holes...........	D18	Drill.........	0.200	0.003

Part name: release cam. Part C118
Material: Steel forging S.A.E. 1045.
Number pieces per assembly: 4.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Normalize and test...	....	H.T		
2	Drill and ream two holes	D18	Drill.........	0.333	0.033
3	Form mill end........	M45	Hand mill....	0.750	0.012
4	Remove milling burrs and burr drilled holes	....	Bench.......	.....	0.010

Operation Sheets

Part name: clutch hub. **Part C119**
Material gray iron casting
Number pieces per assembly 1

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Turn and face hub, bore and ream hole and break sharp corners Turn third dia, cut relief cut chamfers and cut thread	L22	Warner and Swasey	1 500	0 100
2	Face hub and square flange, turn flange and break sharp corners	L36	Lathe	0 600	0 060
3	Mill flats on square flange	M17	Mill	0 750	0 050
4	Broach splines	B33	Broach	0 417	0 020

Part name pressure-plate assembly Part C120
Material parts C114, PC132 and PC134
Number pieces per assembly 1

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Assemble and rivet		Bench		0 112

OPERATION SHEETS

Part name: clutch-drive pin. Part C121
Material: $1\frac{5}{16}$ in. hexagon. C.F.S. S.A.E. 1020, Permit 1120–1112 M.L.
Number pieces per assembly: 4.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Turn, form and cut off	A7	Gridley automatic	5.000	0.019
2	Thread.	L41	Warner and Swasey	0.600	0.005
3	Drill and burr cotter pin hole	D24	Drill.	0.333	0.017

Part name: driven-plate assembly. Part C122
Material: Parts C115, PC132, PC134.
Number pieces per assembly: 1.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Assemble and rivet. . .	. . . .	Bench.	. . . . .	0.112

Part name: flywheel bolt. Part F123
Material: $1\frac{1}{8}$ in. diameter C.F.S. S.A.E. 3135.
Number pieces per assembly: 6.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Round end, turn, thread chamfer head, and cut off	A 7	Gridley automatic	4.000	0.017
2	Remove burr from cut off tool	. . . .	Bench.	. . . . .	0.002
3	Mill flats.	M46	Mill.	0.750	0.010
4	Remove burrs.	. . . .	Bench.	. . . . .	0.006

Operation Sheets

Part name: crankshaft-timing gear key. Part S124
Material: ½ in. square keystock M.L.
Number pieces per assembly: 1.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Saw stock into length 32 in. long	M45	Mill.........	0.750	0.010
2	Turn over 1½ in. of end and weld	....	Forge	.....	0.083

Note. Each bar makes 15 keys which are to be cut off as required at assembly.

Part name: crankshaft-timing gear. Part S125
Material: steel forging S.A.E. 1045.
Number pieces per assembly: 1.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Normalize...........	....	H.T.		
2	Anneal..............	....	H.T.		
3	Rough and finish face rim and hub and rough and finish bore and ream hole, break sharp corners	L2	Potter and Johnson	1.500	0.083
4	Broach keyway......	B33	Lapointe Broach	0.367	0.019
5	Rough and finish turn outside diameter and rough and finish face opposite side, break sharp corners	L9	J. & L.......	1.750	0.100
6	Rough hob teeth.....	H31	Barber Colman	1.017	0.123
7	Finish shape teeth....	H54	Fellows shaper	0.568	0.100
8	Remove burrs and stamp part number	....	Bench.......	.....	0.050

OPERATION SHEET

Part name: crankshaft. Part S126

Material: steel forging S.A.E. 1045, H.T. S.A.E. VII, Brinell 255–217.

Number pieces per assembly: 1.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Layout position of fillets, rough turn line bearings and gear dia. to within 0.030 to 0.035 in. of finished size, form fillets, rough and finish face inside of flange and rough turn oil thd. diameter and turn small end and form radius	L37	Lathe........	2.000	1.333
2	Rough turn pins to within 0.035 to 0.045 in. of finish size	L44	Crankshaft lathe	3.000	0.667
3	Straighten...........	P51	Press........	.....	0.117
4	Face to length, chamfer small end and recenter	L40	Lathe........	0.500	0.050
5	Semi-finish face flange counterbore, relief, recenter and finish turn flange and oil thd. diam. and chase oil thread	L40	Lathe........	1.500	0.800
6	Drill and tap holes in flange	D15	Radial drill ..	0.417	0.150
7	Drill oil holes in cheek	D26	Drill.........	0.500	0.350
8	Grind line bearings...	G28	Norton grinder	0.500	0.568
9	Grind all pin bearings	G29	Norton crank grinder	0.500	0.650
10	Finish face and chamfer flange	L39	Lathe........	0.500	0.100
11	Mill and burr keyway	M49	Mill.........	0.750	0.083
12	Drill and ream starting crank pin hole	D15	Radial drill ..	0.333	0.050

OPERATION SHEET

Part name: flywheel. Part F127
Material: gray iron casting.
Number pieces per assembly: 1.

Operation number	Name of operation	Machine		Standard time, hours	
		Class	Name	Set-up	Per piece
1	Rough and finish face and counterbore flange, rough and finish turn and face rim, round corners, bore and ream hole	M3	Boring mill ..	0.800	0.333
2	Face flange, bore inside of rim, rough and finish face rim on second side and round corners	M3	Boring mill ..	0.600	0.200
3	Drill holes in flange and rim	D11	Multiple drill	0.750	0.066
4	Ream holes in flange, counterbore and tap holes in rim	D15	Radial drill .	0.500	0.200
5	Balance.............	D15	Radial drill ..	0.500	0.100

MACHINE DATA

Machine Class M1

Duplex automatic horizontal mill, 18 in. Cincinnati.
Floor space: 7.25 by 4 feet = 29 sq. ft.
Size of motor: 8 hp.
First cost: $1,000

	Inches
Table feed (working travel of table)..................	18
Total movement of table............................	20
Working surface of table, 9¼ by 30 in.	
Overall dimensions of table, 9¼ by 36 in.	
T-slots in table, three ⅝ in., 2$\frac{5}{16}$ in. centers.	
Maximum distance between spindle noses.............	16
Minimum distance between spindle noses.............	7
Maximum distance between housings.................	20½
Maximum distance top of table to center line of spindle	9
Minimum distance top of table to center line of spindle	3
Vertical adjustment of spindle and tail stock..........	6

Spindle No. 11, B. and S. taper hole, flanged end.
Driven from overhead countershaft.
Manufacturer's recommended drive pulley speed.......500 r.p.m.

Machine Class L2

Chucking lathe, Potter & Johnson model 6A.
Floor space: 10.33 by 4.66 ft. = 48.2 sq. ft.
Size of motor: 7½ hp.
First cost: $2,400.

	Inches
Swing over bed 21⅞ in., swing over cross-slide	13
Turning limit of standard turning tool (diameter)	14
Number of turret faces	4
Travel of cross-slide each way	5
Maximum travel of turret slide	12
Length of turret slide which permits supporting of pilot turret boring tools	5¾
Diameter hole in spindle	3⅝
Manufacturer's recommended drive gear	300 r.p.m.

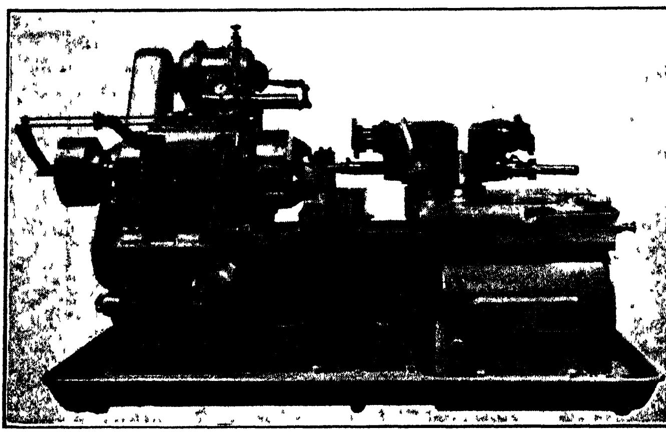


FIG. 131.—Automatic chucking and turning machine with motor drive and air-operated chuck. (*Courtesy of the Potter & Johnson Machine Company.*)

Machine Class M3

Vertical boring mill, 36 in. Bullard, five-face turret, 1 side head.
Floor space: 9.5 by 9 ft. = 85.5 sq. ft.
Size of motor: 10 hp.
First cost: $5,000.

	Inches
Capacity diameter	38
Capacity height under cross-rail	24
Capacity height under turret face	35
Table 34 in. diameter.	
Chuck built into table.	
Vertical head, vertical movement	26

	Inches
Vertical head will face	38 (diameter)
Turret, 15¼ in. diameter, five faces having 2½-in. holes.	
Side-head vertical movement	19
Side-head horizontal movement	20
Top of table to underside of side-head slide	16
Side head has turret tool post four sides.	
Manufacturer's recommended drive pulley	375 r.p.m.

Machine Class A4

Vertical chamfer and cut-off automatic machine, Cone four spindle
Floor space: 18 by 4.33 ft. = 79.9 sq. ft.
Size of motor: 10 hp.
First cost: $3,500.

	Inches
Capacity of collets	1½
Will feed	12
Chamfer and cut-off only.	
Manufacturer's recommended drive pulley	600 r.p.m

Machine Class A5

Automatic screw machine, Cleveland automatic 1¼ in.
Floor space: 9 by 4.5 ft. = 40.5 sq. ft.
Size of motor: 5 hp.
First cost: $1,400.

	Inches
Capacity of collets	1¼
Feed	7¾
Length turned or drilled	7

Machine Class D6

Five-spindle automatic drill, Detroit No. 2.
Floor space: 3.5 by 3 ft. = 10.5 sq. ft.
Size of motor: 3 hp.
First cost: $725.

	Inches
Capacity, drills holes	0 to ⅜
Spindle feed	1¹⁄₁₆
Distance, center line of spindle to table	2⅜
Uses straight shank drills.	
T-slots in table, five ⅝ in., 6-in. centers.	
Fixed spindle centers	6

Machine Class A7

Automatic screw machine, Gridley 2¼-in. special four spindle.
Floor space 19 by 4.66 ft. = 88.5 sq. ft.
Size of motor: 7½ hp.
First cost: $3,500.

2¼-in. machine with 2⅝-in. spindles.

	Inches
Capacity round stock	$2\frac{5}{8}$
Maximum length feed	8
Regular turning length	7
Manufacturer's recommended drive pulley	390 r.p.m.

Machine Class A8

Automatic screw machine, Cleveland $\frac{7}{8}$ in.
Floor space: 15 by 3.5 ft. = 52.5 sq. ft.
Size of motor: 5 hp.
First cost: $1,150.

	Inches
Capacity of collets	$\frac{7}{8}$
Will feed	$7\frac{1}{2}$
Length turned or drilled	$5\frac{1}{2}$

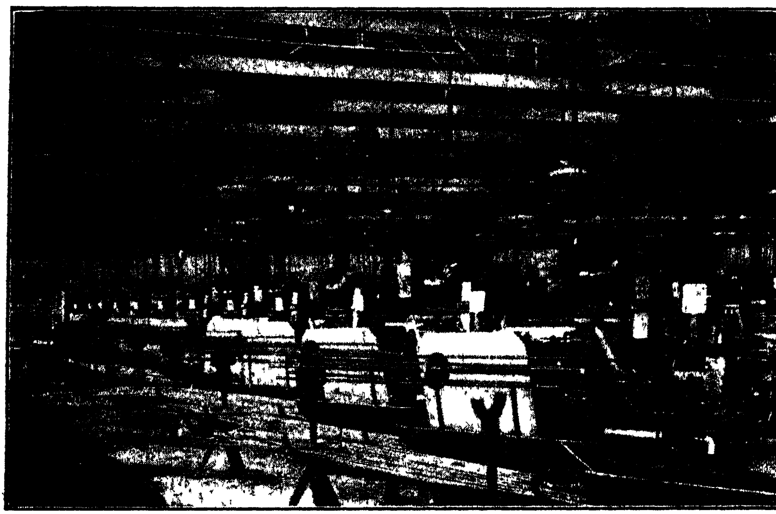


FIG. 132.—A battery of automatic screw machines showing a typical layout. (*Courtesy of the National Acme Company.*)

Machine Class L9

Automatic lathe, Fay 14-in. single carriage.
Floor space: 9 by 3.66 ft. = 32.94 sq. ft.
Size of motor: 10 hp.
First cost: $3,000.

	Inches
Swings over bar	14
Swings over carriage	11
Distance between centers, minimum $5\frac{1}{2}$, maximum	18
Will turn up to 10 in. in length.	
Manufacturer's recommended drive pulley	405 r.p.m.

Machine Class D10

Heavy-duty drill, Foote-Burte No. 25–24 fixed table.
Floor space: 5.5 by 2.3 ft. = 12.7 sq. ft.
Size of motor: 7½ hp.
First cost: $925.

Manufacturer's recommended drive pulley speed........ 350

Machine Class No. D11

Special multiple drill, Baush No. 4. 36 spindle (30 by 38 in.).
Floor space 18 by 9.5 ft. = 171.2 sq. ft.
Size of motor: 25 hp.
First cost: $6,400.

Capacity, twelve, 1¼ in. or twenty-eight, ½-in. drills in C. I.

	Inches
Vertical transverse of head..........................	38
Distance spindle nose to base, minimum 24, maximum	62
Distance spindle center to column, minimum 9, maximum	39
Maximum center distance end spindles......	30 by 46
Minimum distance center of spindles.................	2
Spindles, No. 2 Morse taper, drive tang.	
Vertical adjustment of spindles......................	2½
Head arranged for thirty-six 1¼-in. spindles.	
Base working surface	42½ by 40
T-slots, five 1¹⁄₁₆ in., 8-in. centers.	
Table 36 by 56 in., 25 in. high mounted on track.	

Machine Class D12

Multiple drill, Nacto No. 14, 22 spindle (16 by 24 in.).
Floor space: 6.66 by 3.2 ft. = 21.32 sq. ft.
Size of motor: 10 hp.
First cost: $4,500.

Capacity, twenty-two ⅜-in. drills in C. I.
Capacity, twenty ⅜-in. drills in steel.

	Inches
Vertical traverse of head........	39
Distance spindle nose to base, minimum 1, maximum................................	40
Distance spindle center to column, minimum 7½, maximum................................	23½
Maximum center distance end spindles 16 by 24 in.	
Minimum center distance 1¼-in. spindles........	1⁹⁄₃₂
1½-in. spindles............................	1¹⁷⁄₃₂
Spindles, No. 2 Morse taper, drive tang.	
Spindles have 2-in. vertical adjustment.	
Machine has fourteen 1¼-in. and eight 1½-in. spindles.	
Base working surface....................28 by 31	
T-slots three ¹¹⁄₁₆ in.	
34 in. diameter, rotating table 16 in. high.	
Manufacturer's recommended drive pulley speed. 650 r.p.m.	

Machine Class D13

Multiple drill, Nacto No. 13, 16 spindle.
Floor space: 5.5 by 3 ft. = 16.5 sq. ft.
Size of motor: 7.5 hp.
First cost: $3,500.

Capacity, twelve ½-in. drills in C. I.	Inches
Vertical traverse of head.	19
Distance spindle nose to base, minimum 30, maximum	49
Distance spindle nose to table, minimum 0, maximum	30
Distance spindle center to column, minimum 6, maximum	18
Maximum center distance end spindles.... 12 by	18
Minimum distance center of 1-in. spindles =	1 1/32
1¼-in. spindles =	1 9/32

Spindles No. 2 Morse taper, drive tang.
Spindles have 2-in. vertical adjustment.
Head arranged for 16 spindles.
Base working surface 18 by 19 in.
T-slots, two 9/16 in., 14-in. centers.
Table working surface.................. 17 by 25
Manufacturer's recommended countershaft speed 600 r.p.m.

Machine Class D14

Plain drill, Cincinnati Bickford 28 in.
Floor space: 5.66 by 2.5 ft. = 28.3 sq. ft.
Size of motor: 3 hp.
First cost: $630.

Table working surface.................... 25 in. diameter
T-slots, four 25/32 in., 90-deg. centers.
Table vertical adjustment, 19¼ in.

	Inches
Distance spindle center to column	14½
Maximum distance spindle nose to table	37
Maximum distance spindle nose to base	51¼
Head vertical traverse on column	22¾
Traverse of spindle	12

Spindle No. 4 Morse taper, drive tang.
Base working surface.................... 24 by 24
T-slots in base, two 25/32 in., 12-in. centers.
Manufacturer's recommended drive pulley speed.. 350 r.p.m.

Machine Class D15

Radial drill, 3-ft. Cincinnati Bickford new style.
Floor space: 7.6 by 9 ft. = 68.4 sq. ft.
Size of motor: 5 hp.
First cost: $750.

	Inches
Base working surface	30 by 41
T-slots in base, three $1\frac{3}{16}$ in., $8\frac{1}{2}$-in. centers.	
Distance center-line drill to column in plane of Base, minimum $8\frac{7}{8}$ maximum $36\frac{1}{8}$	
Traverse of spindle on arm	$27\frac{1}{4}$
Spindle No. 4 Morse taper, drive tang.	
Distance spindle nose to base, maximum $50\frac{3}{4}$ minimum $14\frac{1}{4}$	
Traverse of arm on column	$25\frac{1}{2}$
Traverse of spindle	11
Manufacturer's recommended drive pulley speed	525 r.p.m.

Machine Class D16

Sensitive drill, Avey No. $2\frac{1}{2}$, single spindle.
Floor space: 3 by 1.5 ft. = 4.5 sq. ft.
Size of motor: 1 hp.
First cost: $270.

	Inches
Capacity drill diameter	$\frac{7}{8}$
Table working surface	$12\frac{1}{2}$ by 15
Table vertical adjustment	26
Distance spindle center to column	$7\frac{1}{2}$
Traverse of spindle on head	$7\frac{3}{4}$
Traverse of spindle	6
Spindle No. 2 Morse taper, drive tang.	
Manufacturer's recommended drive pulley speed	600 r.p.m.

Machine Class D17

Sensitive drill, Allen 14 in., two spindle.
Floor space: 3 by 3 ft. = 9 sq. ft.
Size of motor: 2.5 hp.
First cost: $315.

	Inches
Table working surface	12 by $26\frac{1}{2}$
Table vertical adjustment	20
Distance spindle center to column	7
Maximum distance spindle to table	25
Traverse of spindle head	$7\frac{1}{2}$
Traverse of spindle	6
Distance between spindle centers	10
Spindle No. 2 Morse taper, drive tang.	

Machine Class D18

Sensitive drill, Avey No. 3, single spindle.
Floor space: 4.5 by 2.1 ft. = 9.4 sq. ft.
Size of motor: 3 hp.
First cost: $350.

	Inches
Traverse of spindle head	13
Traverse of spindle	5
Spindle No. 3 Morse taper, drive tang.	
Manufacturer's recommended drive pulley speed	[illegible]00 r.p.m.

Machine Class L19

Turret lathe, Warner & Swasey No. 2A.
Floor space: 9.5 by 5.33 ft. = 50.6 sq. ft.
Size of motor: 5 hp.
First cost: $2,500.

	Inches
Maximum work swing over ways	16½
Maximum work swing over carriage	13¼
Maximum length turned	29
Scroll chuck jaw capacity	12
Turret diameter across faces	14
Six faces to turret, hole diameter in turret	3¾
Maximum distance face of hexagon turret to end of spindle nose	41
Carriage travel, cross	8½
Carriage travel, longitudinal	24
Manufacturer's recommended drive pulley speed	500 r.p.m.

Machine Class L20

Turret lathe, Warner & Swasey No. 3A.
Floor space: 13 by 6.6 ft. = 85.8 sq. ft.
Size of motor: 15 hp.
First cost: $3,700.

	Inches
Maximum work swing over ways	21½
Maximum work swing over carriage	17¼
Maximum length turned	44
Scroll chuck jaw capacity	16
Turret diameter across faces	17
Maximum distance face of hexagon turret to end of spindle nose	60
Carriage travel, cross	12
Carriage travel, longitudinal	30
Manufacturer's recommended drive pulley speed	440 r.p.m.

Machine Class L21

Turret lathe, Jones & Lamson, two spindle.
Floor space: 8.66 by 5 ft. = 43.3 sq. ft.
Size of motor: 15 hp.
First cost: $2,800.

	Inches
Air chuck equipment.	
Swing when both spindles used	10
Cross travel of head	10½
Hole through spindle	3⅛
Turret 21¾ in. square.	
Traverse of turret	26
Distance between spindle centers	10½
Manufacturer's recommended drive pulley speed	1,200 r.p.m.

Machine Class L22

Turret lathe, Warner & Swasey No. 1A.
Floor space: 9.7 by 5.3 ft. = 51.6 sq. ft.
Size of motor: 5 hp.
First cost: $2,400.

	Inches
Maximum work swing over ways	16¾
Maximum work swing over carriage	13¾
Maximum length turned	26
Scroll chuck jaw capacity	12
Turret diameter across faces	12½
Maximum distance face of hexagon turret to end of spindle nose	35¼
Carriage travel, cross	8¼
Carriage travel, longitudinal (normal)	22¾
Carriage travel, longitudinal (maximum possible)	30½
Turret has overhead pilot heads.	
Manufacturer's recommended drive pulley speed	575 r.p.m.

Machine Class S23

Cut-off saw, Newton No. 199, inserted teeth circular saw.
Floor space: 9.8 by 4.5 ft. = 44.1 sq. ft.
Size of motor: 7.5 hp.
First cost: $800.

	Inches
Thickness of teeth	½
Maximum diameter saw	32
Capacity rounds	9¼ diameter
Capacity squares	8¾

Machine Class D24

Sensitive drill, Allen two-spindle high-speed power feed.
Floor space: 4 by 3.66 ft. = 14.64 sq. ft.
Size of motor: 2.5 hp.
First cost: $800.

	Inches
Capacity drill diameter	$^{29}/_{32}$
Table working surface	$16\frac{3}{4}$ by 30
Table vertical adjustment	16
Distance spindle center to column	8
Maximum distance spindle nose to table	$26\frac{1}{4}$
Traverse of spindle head	$7\frac{1}{4}$
Traverse of spindle	6
Distance between spindle centers	$10\frac{3}{8}$

Spindle No. 2 Morse.

Machine Class D25

Tapping drill, Cincinnati Bickford 21 in.
Floor space: 2.1 by 4.1 ft. = 8.6 sq. ft.
Size of motor: 5 hp.
First cost: $570.

Table working surface .... 19 in. diameter
T-slots, four $^{13}/_{16}$ in., 90-deg. centers.

	Inches
Table vertical adjustment	17
Base	17 by 18
Distance spindle center to column	$10\frac{3}{4}$
Maximum distance spindle nose to column	$29\frac{1}{4}$
Maximum distance spindle nose to base	$46\frac{3}{4}$
Traverse of spindle head	$17\frac{1}{2}$
Traverse of spindle with trip dog	$7\frac{3}{8}$
Traverse of spindle without trip dog	$8^{15}/_{16}$

Spindle No. 3 Morse taper, drive tang.
Manufacturer's recommended drive pulley speed .. 400 r.p.m.

Machine Class D26

Horizontal drill, Avey two-spindle power feed, drills opposed.
Floor space: 9.4 by 2.6 ft. = 24.44 sq. ft.
Size of motor: 1.25 hp. (two motors $\frac{5}{8}$ hp.).
First cost: $1,125.

	Inches
Size of table	$8\frac{1}{4}$ by 63

T-slots, two $\frac{5}{8}$ in., $3\frac{3}{8}$-in. centers.

	Inches
Spindle feed each spindle	11

Spindle No. 2 Morse, drive tang.

	Inches
Maximum distance between spindle noses	35
Distance center line spindle to table	7

Spindles opposed in line.

	Inches
Drill capacity	$\frac{5}{8}$

Spindles have independent Avey-Matic feed.

Machine Class G27

Cylindrical grinder, Norton 14 by 72 in.
Floor space: 17 by 5.5 ft. = 93.5 sq. ft.

Size of motor: 10 hp.
First cost: $3,300.

Will grind.................. 14 in. diameter by 72 in. long

Machine Class G28

Cylindrical grinder, Norton 20 by 96 in.
Floor space: 22 by 6.5 ft. = 143.0 sq. ft.
Size of motor: 15 hp.
First cost: $5,400.

Will grind 20 in. diameter by 96 in. long.
Has overhead countershaft.
Manufacturer's recommended countershaft speed: 600 to 610 r.p.m for 26- and 28-in. wheel.

Machine Class G29

Cylindrical grinder, Norton crank grinder.
Floor space: 20.5 by 6 ft. = 123.0 sq. ft.
Size of motor: 10 hp.
First cost: $3,840.

	Inches
Swing maximum	18
Swing maximum for safety	14
Maximum length inside face of center cradles	56
Maximum length of crankshaft, cradles will take	72

Double drive head and tail stock.

Machine Class G30

Surface grinder, Blanchard.
Floor space: 7 by 4.33 ft. = 30.31 sq. ft.
Size of motor: 22 hp. (two motors; 2 and 20 hp.).
First cost: $4,200.

	Inches
Magnetic chuck diameter	26
Maximum height of work	30
Maximum diameter of work	12

Grinding wheel direct drive on 20 hp., 440 volts.
Alternating-current motor.
Pump and feed driven by 2 hp., 440-volts alternating-current motor.
Magnetic chuck operated on 220-volts direct current.
One direct-current motor generator supplies three machines.

Machine Class H31

Gear hobber, Barber Colman No. 12 (gears and splines).
Floor space: 7.6 by 3.6 ft. = 27.36 sq. ft.
Size of motor: 5 hp.
First cost: $2,400.

	Inches
Capacity, diameter	12
Capacity, width face	10
Capacity, cast-iron, diametral pitch	3
Capacity, steel, diametral pitch	4
Diameter hob spindle	1¼
Maximum diameter hob	4
Hob travel	15

Spindle No. 14 special B. & S. taper, drive none.
2-in. spindle hole equipped with collets.
Standard machine, double arm.
Double thread worm.

Machine Class T32

Trip hammer, Bradley 75 lb.
Floor space: 5.5 by 2.75 ft. = 15.13 sq. ft.
Size of motor 2.5 hp
First cost: $625.

Machine Class B33

Keyseating broach, Lapointe No. 3 single.
Floor space: 16.75 by 2.66 ft. = 44.55 sq. ft.
Size of motor: 5 hp.
First cost: $750.

Capacity to cut keyways up to 1½ in. wide, or broach square holes up to 3 in. across flats from a drilled hole in steel.
Stroke 50 in.
Hole in face plate 5 in. bushed to 4⅜ in.
Manufacturer's recommended drive pulley speed.. 720 r.p.m.

Machine Class B34

Keyseating broach, Lapointe No. 4 single.
Floor space: 20 by 3 ft. = 60 sq. ft.
Size of motor: 5 hp.
First cost: $1,400.

Capacity to cut keyways up to 4 in. wide.
Broaches square holes up to 4 in. across flats from a drilled hole in steel.
Stroke 60 in.
Hole in face plate .... 6 in.
Manufacturer's recommended drive pulley speed.. 450 r.p.m.

Machine Class L35

Centering lathe, Whiton Machine Co., 4 by 86 in.
Floor space: 10.5 by 2.25 ft. = 23.63 sq. ft.
Size of motor: 1 hp.
First cost: $600.

	Inches
Capacity diameter	$\frac{1}{4}$ to 4
Capacity length	$\frac{1}{2}$ to 86
Spindle feed	$1\frac{3}{8}$

Spindle No. 2 Morse special taper.

Machine Class L36

Engine lathe, Le Blond 17 in. by 4 ft. 3 in.
Floor space: 8.6 by 5 ft. = 43.0 sq. ft.
Size of motor: 10 hp.
First cost: $1,750.

	Inches
Swing over bed	$17\frac{1}{4}$
Swing over carriage	$11\frac{7}{8}$
Distance between centers tail stock flush	4 ft. 3 in.
Spindle-hole diameter	$1\frac{5}{16}$
Centers No. 4 Morse.	
Screw cutting.	
Turret tool post	1 by $1\frac{7}{8}$
Manufacturer's recommended countershaft speed,	175 and 210 r.p.m.

Machine Class L37

Engine lathe, American.
Floor space: 10 by 3.5 ft. = 35 sq. ft.
Size of motor: 10 hp.
First cost: $1,100.

	Inches
Swing over bed	$20\frac{1}{2}$
Swing over carriage	$13\frac{1}{4}$
Distance between centers tail stock flush	4 ft. 3 in.
Centers No. 4 Morse taper.	
Spindle-hole diameter	$1\frac{1}{2}$
Screw cutting.	
Turret tool post	$1\frac{7}{8}$ by $1\frac{1}{4}$ in.
Manufacturer's recommended countershaft speed	168 and 211 r.p.m.

Machine Class L38

Engine lathe, Le Blond 17 in. by 4 ft.
Floor space: 8.6 by 5 ft. = 43 sq. ft.
Size of motor: 10 hp.
First cost: $1,750.

	Inches
Swing over bed	$17\frac{1}{4}$
Swing over carriage	$11\frac{7}{8}$
Distance between centers tail stock flush	4 ft. 3 in.
Spindle-hole diameter	1 ft. $\frac{5}{16}$ in.

Centers No. 4 Morse.	
Screw cutting.	
Turret tool post	1 by 1⅞ in.
Manufacturer's recommended countershaft speed	175 and 210 r.p.m.

Machine Class L39

Engine lathe, Le Blond 19 in. by 5 ft. 8 in.
Floor space: 11 by 4 ft. = 44 sq. ft.
Size of motor: 15 hp.
First cost: $2,060.

	Inches
Swing over bed	19½
Swing over carriage	14
Distance between centers tail stock flush	5 ft. 8 in.
Centers No. 5 Morse taper.	
Spindle-hole diameter	1½ in.
Screw cutting.	
Turret tool post	1 by 1⅛ in.
Manufacturer's recommended countershaft speed	175 and 210 r.p.m.

Machine Class L40

Engine lathe, American.
Floor space: 14.5 by 3.5 ft. = 50.75 sq. ft.
Size of motor: 15 hp.
First cost: $1,530.

	Inches
Swing over bed	24½
Swing over carriage	17½
Distance between centers tail stock flush	7 ft. 10 in.
Centers No. 4 Morse taper.	
Spindle-hole diameter	1¾ in.
Screw cutting.	
Turret tool post	1½ by 2 in.
Medium pattern.	
Manufacturer's recommended countershaft speed	220 and 272 r.p.m.

Machine Class L41

Hand screw machine, Warner and Swasey No. 4 universal for bar stock.
Floor space: 11 by 2.6 ft. = 28.6 sq. ft.
Size of motor: 2.5 hp.
First cost: $1,200.

	Inches
Swing over bed	16
Swing over carriage	14¼
Swing over cross-slide	8½
Threading capacity soft steel	1¼
Automatic chuck capacity round	1½
Automatic chuck capacity hexagon	1$\frac{5}{16}$
Automatic chuck capacity square	1$\frac{1}{16}$
Hole in automatic chuck plunger	1$\frac{9}{16}$
Carriage cross-travel	8
Carriage longitudinal travel	17
Maximum length turned with hexagon turret	10
Maximum distance end of automatic chuck to turret	23
Holes in hexagon turret	1½

Hand and power feed on carriage, turret and cross-slide.

Machine Class L42

Hand screw machine, Southworth No. 4 with bar stock equipment.
Floor space: 11 by 2.6 ft. = 28.6 sq. ft.
Size of motor: 2.5 hp.
First cost: $800.

	Inches
Swing over bed	16
Swing over carriage	14
Swing over cross slide	7
Automatic chuck capacity round	1½
Automatic chuck capacity hexagon	1$\frac{5}{16}$
Automatic chuck capacity square	1$\frac{1}{16}$
Carriage cross-travel	8
Maximum length turned with hexagon turret	10
Maximum distance end of automatic chuck to turret	23
Holes in turret	1½

Hand feed on carriage and turret.

Machine Class L43

Special lathe, Lo-swing 8 by 61 in.
Floor space: 9.5 by 3 ft. = 28.5 sq. ft.
Size of motor: 10 hp.
First cost: $1,500.

	Inches
Swing	8
Distance between centers, tail stock flush	61

Two carriages 18 in. long.
Manufacturer's recommended drive pulley speed.. 500 r.p.m.

Machine Class L44

Crankshaft lathe, Lodge & Shipley.
Floor space: 14 by 4 ft. = 56 sq. ft.
Size of motor: 7.5 hp.
First cost: $4,600.

	Inches
Swing over bed	28
Swing over carriage	17
Distance between head-stock and tail-stock plate, tail-stock flush	77
Turret tool post, three-way special tools.	
Drives on both head and tail stock.	
Overhead bar to locate crankshaft.	
Stops for carriage.	

Machine Class M45

Hand mill, Whitney No. 6.
Floor space: 4 by 2.5 ft. = 10.0 sq. ft.
Size of motor: 3 hp.
First cost: $300.

	Inches
Table working surface	20 by 4½
T-slots, one	⅝
Range longitudinal lever	6
Range longitudinal crank	14
Range traverse	6
Spindle No. 9 B. & S. taper.	
Distance center-line spindle to table, minimum 0, maximum	15½
Vertical spindle adjustment	4
Vertical knee adjustment	11½

Machine Class M46

Plain mill, Brown & Sharpe No. 12.
Floor space: 5.8 by 3.6 ft. = 20.9 sq. ft.
Size of motor: 10 hp.
First cost: $730.

	Inches
Table working surface	29 by 6
T-slots, one	⅝
Range longitudinal	26
Range traverse	0
Spindle adjustment longitudinal	⅝
Spindle range vertical	9
Spindle No. 10 B. & S. taper, drive tang.	

Machine Class M47

Plain horizontal mill, Cincinnati No. 5.
Floor space: 12.5 by 10.66 ft. = 133.25 sq. ft.

Size of motor: 15 hp.
First cost: $4,200.

	Inches
Table overall	83 by 21
Table working surface	79 by 21
T-slots, three ¾ in., centers	5
Range longitudinal	50
Range cross	14
Range vertical	21

Spindle will run either direction.
Spindle No. 12 B. & S. taper drive.
Cincinnati standard flanged end.
Manufacturer's recommended drive pulley speed.. 600 r.p.m.

Machine Class M48

Horizontal mill, Cincinnati No. 4.
Floor space: 12.5 by 7.25 ft. = 90.63 sq. ft.
Size of motor: 10 hp.
First cost: $3,400.

	Inches
Table over all	68¼ by 16½
Table working surface	64¼ by 16½
T-slots, three ¾ in., centers	3¾
Range longitudinal	42
Range cross	14
Range vertical	20

Spindle No. 12 B. & S. taper drive.
Standard flanged end.
Manufacturer's recommended pulley speed.... 325 r.p.m.

Machine Class M49

Key seat milling machine, Burr No. 5, 60 in.
Floor space: 10.66 by 3.75 ft. = 39.98 sq. ft.
Size of motor: 5 hp.
First cost: $880.

	Inches
Table over all	66 by 9
Table working surface	60 by 9
Table feed longitudinal	60
Distance center line horizontal spindle to table maximum	11½, minimum 4

Horizontal spindle will take cutters 1½-in. hole up to 5 in. diameter.
Vertical spindle has 3¼-in. vertical adjustment.
Distance vertical spindle nose to horizontal spindle center line.................. 1¾ in. below, 1½ in. above
Vertical spindle has No. 7 B. & S. taper.
Vertical spindle has horizontal adjustment of 1 in.
T-slots, three ⅝ in., 3-in. centers.

Machine Class M50

Plain horizontal mill, Milwaukee No. 4B (special-length table).
Floor space: 12.25 by 9.5 ft. = 116.37 sq. ft.
Size of motor: 15 hp.
First cost: $4,440.

	Inches
Table working surface	88 by 18
T-slots, three 13/16 in., 4-in. centers.	
Range longitudinal	52
Range traverse	14
Range vertical	20
Spindle No. 12 B. & S. taper, drive lugs.	
Spindle runs either direction.	
Double-head attachment distance between cutters, minimum 6, maximum, 24	
Manufacturer's recommended motor 15 hp. speed	1,200 r.p.m.

Machine Class P51

Vertical hydraulic press, Logeman 50 ton.
Floor space: 9.5 by 5.66 ft. = 53.77 sq. ft
Size of motor: 5 hp.
First cost: $1,025.

Capacity	50 tons
	Inches
Width between tension rods	21
Maximum opening table to ram	27
Maximum stroke of ram	18

Machine Class P52

Punch press, Williams & White No. 14½, double.
Floor space: 9.33 by 4.5 ft. = 41.98 sq. ft.
Size of motor: 10 hp.
First cost: $1,000.

	Inches
Stroke	1½
Die space	10
Ram face	5¼ by 15
Size of table	10½ by 20
Size of hole in table	3 by 6
Throat distance inside ram to column	6 by 17½
Capacity punch	1-in. hole in 1-in. plate.
Capacity shear	¾ in. round
Capacity	4 by 4 by 7/16 in. angle
Capacity splitting	⅞-in. plate
Manufacturer's recommended strokes	30 per minute

Machine Class P53

Power shears, Niagara 66-in. by 10- gage.
Floor space: 10.5 by 6.66 ft. = 69.9 sq. ft.
Size of motor: 10 hp.
First cost: $475.

Capacity soft steel..........	10 gage or lighter
Length of blades......................	66 in.
Throat distance......................	15 in.
Manufacturer's recommended drive pulley speed.........................	250 r.p.m.

Machine Class H54

Follows gear shaper, No. 612 standard.
Floor space: 6 by 4.5 ft. = 27 sq. ft.
Size of motor: 8 hp.
First cost: $1,400.

Capacity spur gears: 35 in. outside diameter, four pitch 14½-deg. pitch angle, or three-fourth pitch 20-deg. pitch angle, 5-in. face.
Capacity internal gears: 25 in. inside diameter, four pitch 14½-deg. pitch angle, or three-fourths pitch 20-deg. pitch angle, 3-in. face.
Maximum cutter 4 in. pitch diameter.
1¾-in. hole in work spindle.
Distance bottom of saddle to work spindle bushing end 5⅞ in.
Distance center-line cutter slide to center-line work spindle: For spur gears, minimum 0 in., maximum, 20½ in. For internal gears, minimum 0 in., maximum, 10½ in.
Distance cutter slide nose to work spindle bushing end: minimum 2⅛ in., maximum, 7 in.
Manufacturer's recommended countershaft speed. 605 r.p.m.

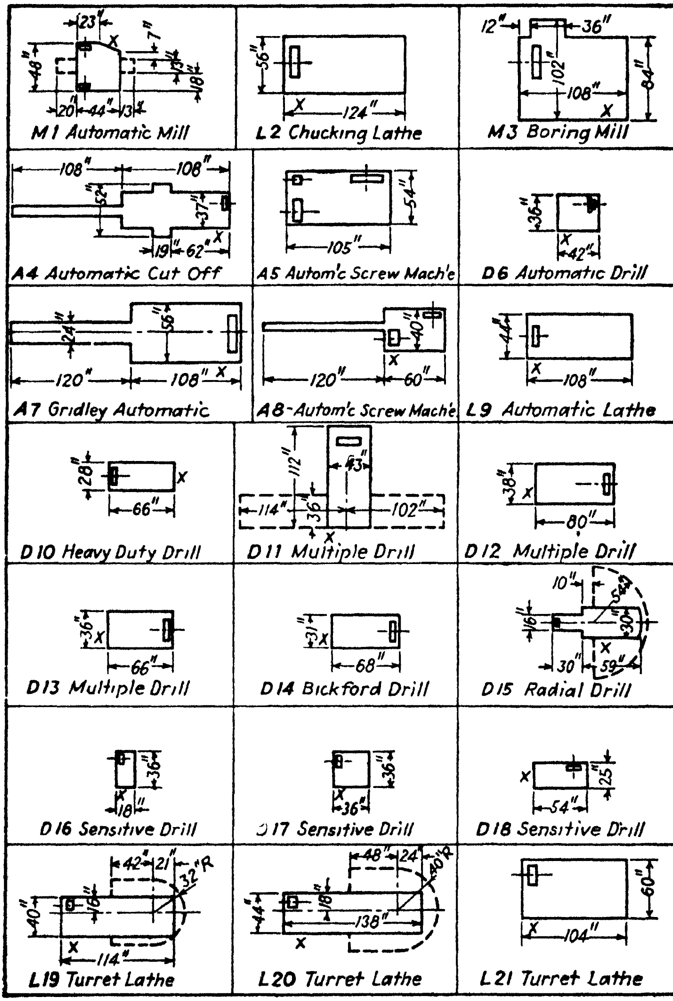
Machine Class P55

Punch press, Consolidated Press Co. No. 5 back geared inclinable.
Floor space: 5.1 by 4 ft. = 20.4 sq. ft.
Size of motor: 8 hp.
First cost: $1,400.

	Inches
Throat distance..................................	8½
Distance between columns.........................	13
Stroke..	3

Machine Class X56

Bench.
Floor space: 2.5 by 5 ft. = 12.5 sq. ft.
Size of motor: 0.
First cost: $25.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L 2 Chucking Lathe
M 3 Boring Mill
A 4 Automatic Cut Off
A 5 Autom'c Screw Mach'e
D 6 Automatic Drill
A 7 Gridley Automatic
A 8-Autom'c Screw Mach'e
L 9 Automatic Lathe
D 10 Heavy Duty Drill
D 11 Multiple Drill
D 12 Multiple Drill
D 13 Multiple Drill
D 14 Bickford Drill
D 15 Radial Drill
D 16 Sensitive Drill
17 Sensitive Drill
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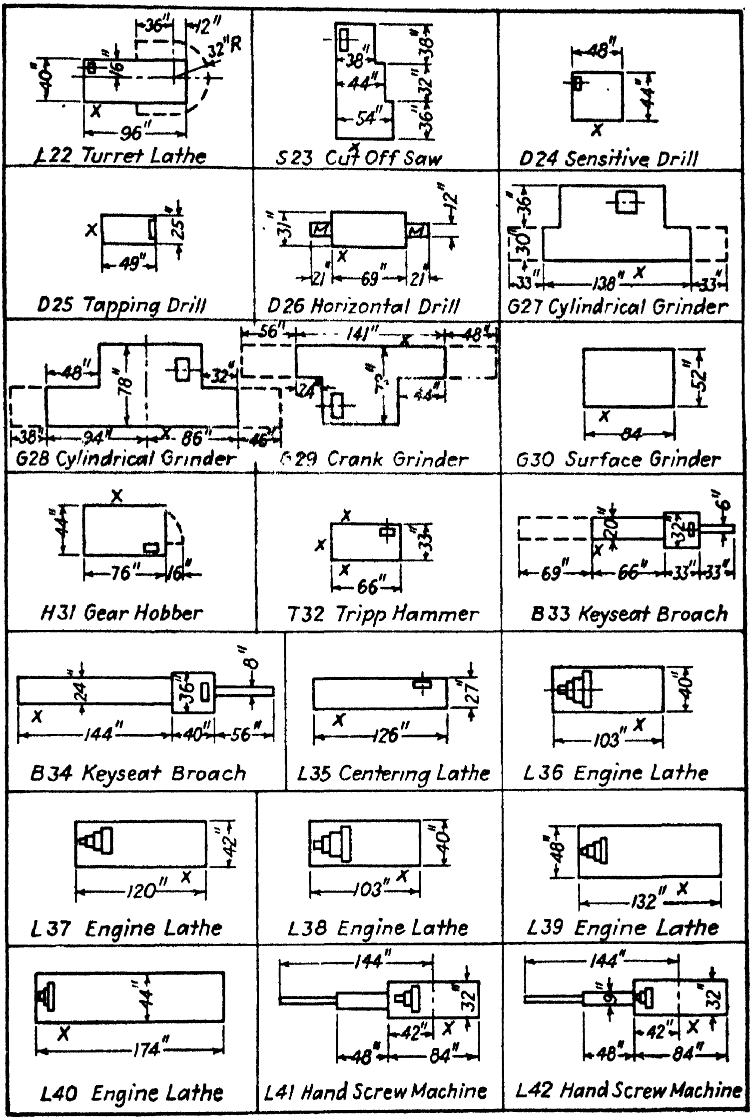
L 19 Turret Lathe
L 20 Turret Lathe
L 21 Turret Lathe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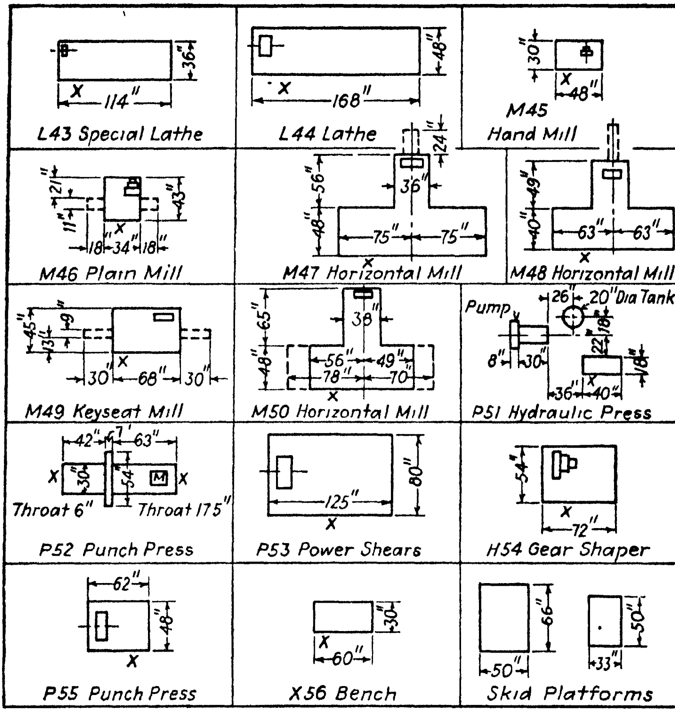
S23 Cut Off Saw
D24 Sensitive Drill
D25 Tapping Drill
D26 Horizontal Drill
G27 Cylindrical Grinder
G28 Cylindrical Grinder
G29 Crank Grinder
G30 Surface Grinder
H31 Gear Hobber
T32 Tripp Hammer
B33 Keyseat Broach
B34 Keyseat Broach
L35 Centering Lathe
L36 Engine Lathe
L37 Engine Lathe
L38 Engine Lathe
L39 Engine Lathe
L40 Engine Lathe
L41 Hand Screw Machine
L42 Hand Screw Machine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L44 Lathe
M45 Hand Mill
M46 Plain Mill
M47 Horizontal Mill
M48 Horizontal Mill
M49 Keyseat Mill
M50 Horizontal Mill
P51 Hydraulic Press
Pump
20" Dia Tank
P52 Punch Press
Throat 6"
Throat 17.5"
P53 Power Shears
H54 Gear Shaper
P55 Punch Press
X56 Bench
Skid Platforms

APPENDIX B

DETERMINATION OF ECONOMIC LOT SIZES[1]

"To obtain the lowest cost of production which will be a minimum for a given business situation and permit a conservative use of capital, equal emphasis must be placed upon the interests of the financial and sales executives as well as upon those of the production executive. The first insists upon small inventories, a rapid turnover of capital, and low costs; the second demands an attractive and diversified line of products, prompt deliveries, and a price low enough to meet competition.

"Coordination of these various factors can easily be achieved in industries where continuous lines of production have been adopted, because, when raw materials can be made to flow through a sequence of closely related manufacturing operations without interruption at a rate equal to that for the sales demand, the problems of inventories and machine change-over are automatically eliminated. However, in other industries or companies it may be inadvisable to adopt such methods owing to a wide diversification of products which must be supplied in a variety of sizes to a more or less limited market. Likewise, rapid style changes and design obsolescence will influence the arrangement of manufacturing schedules which may best avoid the accumulation of a large number of unsalable articles should the demand suddenly shift. Moreover, it is quite possible that the additional amount of capital, required to carry on production on a larger scale, is not available, and the financial position of the company may not warrant borrowing the necessary funds.

"In any of these cases, intermittent methods of production must continue. This means that all products must be manufactured in lots or quantities of convenient size. The processing of any lot will naturally involve a cost for setting up and dis-

[1] RAYMOND, F. E., Economic Lot Sizes, *Factory and Ind. Management*, vol. 80, No. 1, p. 39, July, 1930, reproduced by permission of the author and publisher.

mantling the manufacturing equipment, which, together with that for production control, will create a charge that must be prorated to the entire group of articles. Similarly, a charge will arise from the cost of carrying the inventory, which will increase in proportion to the amount of stock required in anticipation of the sales demand when the equipment has been shifted to the production of other articles. This will continue until the stock of the original article has been reduced to the order point, whereupon the cycle will repeat itself. If the size of the lot be too small, the ultimate unit cost for the lot will be increased beyond all reason, because too large a proportion of the preparation costs will have to be borne by each unit of production. On the other hand, if the lot be too large, inventories will be built up and the rate of capital turnover will consequently decrease.

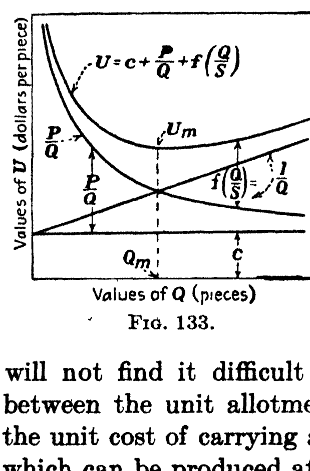


FIG. 133.

Where should the production executive draw the line in determining the best lot size if he is to satisfy the interests of the sales and financial divisions of his concern as well as his own? He will not find it difficult if he recognizes an economic balance between the unit allotment of the total preparation costs and the unit cost of carrying articles in inventories, for the quantity which can be produced at a minimum ultimate unit cost. This fact may be demonstrated graphically by reference to Fig. 133, where it may be seen that the minimum point of the ultimate unit-cost curve U, which contains all the charges which accrue to an article up to the instant it is finally removed from inventories, lies directly over the intersection of the curve for the unit-preparation cost P/Q and the straight line $I/Q = f(Q/S)$ representing the unit investment and storage charges. In other words, the same quantity or lot size will satisfy both situations, and this specific one should be the best from a cost standpoint alone.

"If this relation be expressed mathematically, it will be found that

$$\frac{P}{Q} = f\left(\frac{Q}{S}\right) \tag{1}$$

where

Q = best lot size in pieces.
P = total preparation cost in dollars.
S = yearly rate of consumption in pieces per year.
f = unit investment and storage charge factor, in dollars per piece per year.

so that if this expression be solved for Q, the minimum cost quantity will become

$$Q = \sqrt{\frac{PS}{f}}. \tag{2}$$

"As a result of extended investigation into the practical application of this general formula, it has been found that the factor f should be made up of three elements ($K_s + K_w + K_v$), instead of only one, as has been the usual practice in the past. Formerly, all expressions for the minimum cost quantity were based upon the element K_s, which represents the investment charge for carrying finished goods or their component parts in stores and can be written as

$$K_s = \frac{c \times i}{2}\left[1 - \frac{S}{D}\left(1 - \frac{1}{n}\right)\right] \tag{3}$$

where

c = unit production cost, composed of the unit cost of material, direct labor, and its overhead in dollars per piece.
i = interest rate per year (decimal per year).
D = rate at which articles can be delivered to stores in pieces per year.
n = number of batches or subdivisions of the production lot, if any.

"Recently, cases have been encountered in which the bulk of the finished article was so large in proportion to its dollar value that it was necessary to take into account the charges which accumulated on the space occupied by the article while in stores, as well as cost of capital. The element can be written as

$$K_v = \left[\frac{s \times b}{h} 1 - \frac{S}{D}\left(1 - \frac{1}{n}\right)\right] \tag{4}$$

where

s = space charge in dollars per square foot.
b = bulk of the article in cubic foot per piece.
h = average height to which storage is permissible on each square foot of floor space in feet.

"Finally, it has been found that the cost of capital does not arise entirely from that invested in stores inventories, because there are naturally comparatively large amounts of capital which are similarly invested in work in process. If the correct investment charge is to be employed in the determination of the best lot size, the cost of capital as derived from all sources must be fully accounted for. Accordingly, the element K_w must be included as well and can be written as

$$K_w = \left(\frac{m + c}{2}\right)Sti \tag{5}$$

where

m = unit cost of raw material only in dollars per piece.

t = average time for one piece to complete the cycle of manufacturing operations.

"If these three elements be now introduced in place of the factor f, the general expression for the minimum cost quantity becomes

$$Q_m = \sqrt{\frac{PS}{\frac{ci}{2}\left[1 - \frac{S}{D}\left(1 - \frac{1}{n}\right)\right] + \left(\frac{m + c}{2}\right)Sti + \frac{bs}{h}\left[1 - \frac{S}{D}\left(1 - \frac{1}{n}\right)\right]}}. \tag{6}$$

The actual mathematical derivation of this expression is quite complicated and would serve no real purpose should it be given here. It cannot be too strongly emphasized that the use of abbreviated expressions is extremely dangerous, as experience with a wide variety of applications to various types of problems has conclusively shown that all elements must be considered if a reliable means of production control is to be obtained in this manner. However, it will be demonstrated later that when the factors governing a given situation are specified, this general expression can be simplified by the omission of those elements which are obviously of little or no importance. Such treatment, when properly employed, will greatly shorten the labor of calculation and still yield results that will be found to approximate closely those which would have otherwise been obtained from the general formula.

"The fact is that minimum cost quantities do not yield the true economic lot size, because in their derivation only the

view points of the production and sales executives have been considered. The interests of the financial executives will be introduced into the formula to show how capital can be properly conserved and, at the same time, a flexibility of production schedules maintained to permit adjustments to changes in the sales demand.

"To demonstrate more conclusively how the manufacturing and financial policies interlock, and to permit a better understanding of this new concept of the economics of manufacture, we shall consider a concrete example. Let it be assumed that $220,000 worth of business can be obtained in a year from the sale of a specific product on an initial investment of $100,000 upon which a return of 10 per cent is earned.

"The gross return, then, will be $20,000 because the initial capital must be turned over twice a year. Now let the lot size be reduced to a point where the same amount of yearly business can be done on an investment of only $25,000. Again, assuming that a greater return than 10 per cent cannot be earned on account of the severity of competition, the profit on each turnover of capital will naturally be only $2,500. However, the size of this lot will permit an inventory turnover of eight times a year, and this will bring the gross return back to the original $20,000. Obviously, the smaller quantity will be the better lot size from the financial executive's point of view, because, by an average expenditure of only $25,000 maintained throughout the year, each dollar thus invested will return 80 cts. profit, whereas, when the average capital expenditure was $100,000, the return on each dollar was only 20 cts.

"If, in this example, minimum cost production can be obtained only for the lot size which requires an investment of $100,000 to finance the manufacturing operations, because of the nature of the product and process and the extent of the sales demand, it is at once evident that a smaller production quantity could not be produced for so low a cost. Now, if any benefit is to be derived from the conservation of capital by the production of a lot whose size will permit the average investment to be reduced from $100,000 to $25,000, the natural increase in cost must be offset in some manner so that the same gross return will be earned as in the first case. Obviously, if this can be achieved, a truly economical manufacturing situation can be attained which

should satisfy not only the production and sales executives but also the financial executives, and the lot size which will meet these requirements can then be justly designated as the economic production quantity.

"If the annual gross return be prorated to each unit of product sold, it is not a difficult matter to demonstrate that the increase in unit cost due to the production of a smaller lot can be offset by an equivalent reduction in the unit margin of profit; especially as it can be seen from the foregoing example that the gross return bears a definite relation to the capital invested in the manufacture of any single lot, and the number of times this initial investment is turned over during the year. Furthermore, it can be shown that the initial capital investment is, in reality, a function of the value of each unit produced and the size of the lot, provided that an adjustment of the fixed capital represented by the manufacturing facilities employed in the process is made by the introduction of an appropriate constant R_f. As a result, it will be found that the unit margin of profit, which for any lot size will insure the same gross return, is directly proportional to the quantity produced.

"Now if Fig. 134 be referred to, where the curve U represents the summation of the corresponding values at any point on the curve $\frac{P}{Q}$ and the lines $\frac{I}{Q} = f\frac{Q}{S}$ and c, as described in connection with Fig. 133 and if the values of the unit margin of profit (R/S)[1] be subtracted from the minimum sales price represented by the horizontal line p, from which the cost of conducting the business has been already deducted, a line U_L sloping downward can be drawn which will indicate the extent to which any value on the curve U may be increased, as occasion demands, without impairing the annual gross return R. Moreover, if the spread between cost and price or any quantity produced is to be so regulated as to adhere to the basic assumption with regard to the gross return, it is obvious that the line U_L must pass through the minimum point of the ultimate unit cost curve U at Q_m. Accordingly, as the line U_L is at all times straight, because it depends directly upon the lot size Q, it must intersect the curved line U of actual unit cost at another point as well. This second point of intersection will be for a smaller lot size and, as it lies on both the curves U and U_L,

[1] Where S represents the total anticipated sales for the year.

it is evident that the increase in cost $L = (U_e - U_m)$ can be exactly offset by the permissible reduction in the unit margin of profit $[(R/S)_m - (R/S)_e]$ so that the gross return for the year can still be maintained at an amount equal to that for the minimum cost quantity. Since this lot size meets the requirements imposed by the financial as well as the production and sales executives, it can be designated as the economic production quantity.

"Before turning to the derivation of a method of computing this quantity for use in the daily control of production, it is important to note that over the range between the economic quantity Q_e and the minimum cost quantity Q_m the curve U_L lies above the curve U. This fact indicates that the actual cost of all manufacturing operations for any quantity within this range will permit a unit margin of profit greater than that necessary to yield gross return equal to that at minimum cost. If this be so, any production quantity within this range can be employed in the scheduling of production in accordance with any reasonable fluctuation in the sales demand, without requiring any computations to check the reliability of the quantity so selected. This provides a marked degree of flexibility, which opens up an excellent opportunity for the automatic regulation of manufacturing operations within limits which definitely insure an adequate profit without requiring too close a daily supervision of manufacturing costs. Therefore, any quantities lying between the economic and minimum cost quantities will henceforth be designated as constituting the economic range of production.

"Since it is possible to justify the conservation of capital and to provide a greater degree of flexibility by the determination of the limits for economical production, it will be of much advantage to introduce some method of determining accurately the economic production quantity Q_e, which will be parallel to that already devised for computing the minimum cost quantity Q_m. This can be accomplished by employing the relations graphically illustrated in Fig. 134. However, any attempt to carry through the various steps involved in deriving such a mathematical expression would defeat the purpose of this article, because it is intended here only to emphasize the fundamental principles underlying this new concept of the economic aspect of manufacture. Accordingly, the various steps will

have to be taken for granted, but it can be stated on excellent authority that the correct value for use in solving practical problems in industry may be obtained from the formula where

$$Q_e = \sqrt{\frac{PS}{(K_s + K_w)\,K_r + K_v}} \tag{7}$$

and

$$k_r = 1 + 2\frac{r}{i} + \frac{r^2}{i^2\left[1 + \dfrac{K_v}{K_s + K_w}\right]}.$$

If this general relationship be expanded by the introduction of the individual expressions for the elements K_s, K_w, and K_v

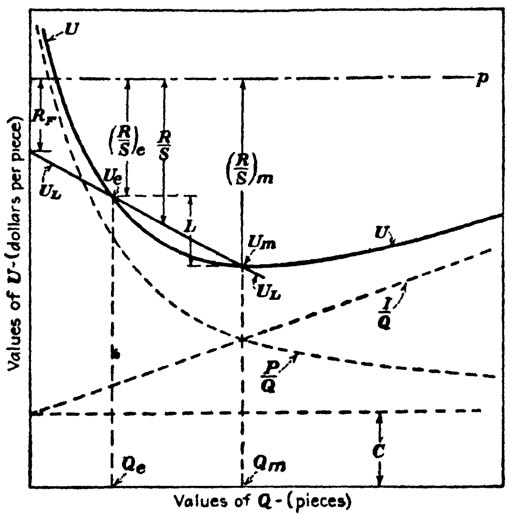


FIG. 134.

in the denominator as derived in the first part of this appendix, a universal equation may be written where

$$Q_e = \sqrt{\frac{PS}{\left\{\frac{ci}{2}\left[1-\frac{S}{D}\left(1-\frac{1}{n}\right)\right]+\left(\frac{m+c}{2}\right)Sti\right\}\cdot\left\{1+2\frac{r}{i}+\dfrac{r^2}{i^2\left[1+\dfrac{2bs}{hi\left[c+\dfrac{(m+c)t}{\left(\frac{1}{S}-\frac{1}{D}\right)\left(1-\frac{1}{n}\right)}\right]}\right]}\right\}+\frac{bs}{h}\left[1-\frac{S}{D}\left(1-\frac{1}{n}\right)\right]}} \tag{8}$$

"It is well recognized that this mathematical expression may appear so formidable as to be of little practical utility, not only because lengthy and tedious calculations are implied, but also because subordinates in the production-control department

are unfamiliar with their treatment. This practical aspect of the problem has been in no wise overlooked, because methods of simplification will be derived and their utility demonstrated which will permit anyone to make the necessary computations. In fact, by this procedure both the formulas for the economic production quantity and the minimum cost quantity can be reduced to a simple form which in most cases need employ but five or six variables, and in extreme cases only three—permitting the adoption of mechanical means of solution such as slide rules and charts.

"Even though simplified formulas for the determination of the lot size will be of definite advantage, care must be exercised in the selection of the one which will be appropriate for use in any specific case. If the wrong formula be employed, erroneous results will be obtained because the elements upon which it is

TABLE XXXVII.—DATA COLLECTION SHEET FOR ECONOMIC LOT-SIZE DETERMINATIONS

Item 1. Unit material cost (m) = \$......per piece.

Operation number	Unit operation time, hours	Unit labor cost, dollars per piece	Overhead, dollars per piece	Machine change-over cost, dollars	Number of batches
1.............					
2.............					
3.............					
4.............					
Etc...........					(n)
Last..........	....	....	....	....	[Item 2]
Totals.......	t_o	l	o	M	

Item 3. Unit production cost $c = l + o =$ \$........per piece.
Item 4. Total production control cost per lot $G =$ \$........
Item 5. Total preparation cost $P = M + G =$ \$........
Item 6. Unit process time $t = t_o \div$ (number of working hours per day $\times$ number of working days per year) so that $t =$ ....years per piece.
Item 7. Rate of consumption $S =$ ....pieces per year.
Item 8. Rate of delivery to stores $D =$ ....pieces per year.
Item 9. Interest rate i per cent per year $\div$ 100 = ...
Item 10. Expected rate of return r (per cent per year $\div$ 100) = ...
Item 11. Unit storage space charge $s =$ \$........per square feet per year.
Item 12. Overall volume of article $b =$ ....cu. ft.
Item 13. Overall height for storage $h =$ ....ft.

based have, in all probability, little or no influence upon the actual quantity which ought to be produced to achieve the desired economical conditions.

"For instance, when the simplest formula which has been developed so far is applied to a product for which there is only a moderate demand and which involves a comparatively large preparation cost, mainly owing to the complicated machine set-ups required, a reliable value for the lot size can be obtained. However, if this same formula be applied to a product which requires a relatively long time for the processing of the lot in comparison with the time any unit thus produced will remain in stores inventories, the resulting lot size will be utterly unreliable. The reason for this lies in the fact that the cost of the capital invested in work in process is the controlling element, and not the inventory charges incurred upon articles in stores, as was true in the first case. Similarly, if this original formula be applied to a product similar to furniture or automobile bodies, where the ratio of its volume to its value is large in contrast to such a ratio for a product similar to a high-grade watch, the economic balance will no longer depend upon the investment charges but upon the cost of storage space.

"Consequently, since the characteristics of any unit of production, as well as the method employed in its manufacture, in one industry may differ from those for any other, the lot size should be determined by the use of the simplest formula which takes into account the specific characteristics pertaining to the particular type of industry. The resulting formulas will be no more complex than the one first referred to, unless the controlling factors are unduly interrelated. The problem, therefore, resolves itself merely to the selection of the single unit-cost element which can be employed in the denominator of either of the formulas for the economic production quantity or the minimum cost quantity that is responsible for the greater portion of the total unit charges derived from the cost of capital and storage space. In some rare instances, however, no single element can be found that alone controls the situation. Then two elements must be employed.

"These elements are identical with those in the first part of this appendix where the composition of the factor f was discussed in the derivation of the minimum cost quantity. In order to develop a reliable means for selecting the appropriate element for

Table XXXVIII.—Calculation Sheets

Part I. Procedure for the Selection of Simplified Formulas

A. Preliminary Facts

Item 1. Divide s by i and multiply by $2/h$.

NOTE. Item 1 is a constant for all problems in a given plant.

Item 2. Subtract the ratio $\frac{S}{D}$ multiplied by k_p from 1

where $k_p = 0$ for non-continuous production.
$k_p = 1$ for semicontinuous production.
$k_p = (1 - 1/n)$ for batch production.

B. Computation of Rates

Item 3. Divide b by c.
Item 4. Multiply item 1 by item 3 to find index ratio R_v.
Item 5. Divide S by item 2.
Item 6. Divide m by c and add 1.
Item 7. Multiply item 5 by item 6 by t to find index ratio R_w.
Item 8. The constant 1.0 designated as "index ratio R_s."
Item 9. Add items 4, 7, and 8 to obtain index ratio R_c.
Item 10. Compare index ratios R_v, R_w, and R_s (items 4, 7, and 8) and select the one or two the value of which is or are equal to at least $\frac{2}{3}$ R_c (or 2/3, item 9), and choose the simplified formula in Table XXXIX, which depends upon this index or these indexes, as shown in the column of conditions of use.

Part II. Procedure for Determining the Allowable Variation and the Form Index f_c (Optional)

Item 11. Multiply item 9 by i by 2.
Item 12. Divide item 5 by item 11.
Item 13. Divide c by P.
Item 14. Multiply item 12 by item 13.
Item 15. Find the square root of item 14.
Item 16. Add 1 to item 15 to find "problem index" K_o.
Item 17. See Fig. 135. Select curve in portion of chart to the right of line M for an allowable percentage increase λ in unit cost over the minimum cost and locate point on bottom scale for values of the form index f_c below the point of intersection of the appropriate curve for λ with the horizontal line drawn through the value of the problem index K_o (item 16) on the vertical scale.
Item 18. Read off the decimal figure for the form index f_c, and this number may be used in place of the ratio $\frac{2}{3}$ in item 10 (Part I) to aid in the selection of the appropriate formula, if greater accuracy is desired.

use in a given problem which will require the least effort, a series of index ratios have been established for comparing the relative importance of each element one with another, as well as with the total of all combined. As a result, all the items common to any two of the elements, the relation of which is

desired, can be eliminated, and a direct comparison can then be obtained between those items which actually control each situation. As a matter of fact, it is necessary only to evaluate two such ratios because, if the most frequently used element be employed throughout as a common denominator, the relative importance of all three can be demonstrated immediately. Moreover, there will never be occasion to evaluate the ratio for all the elements together because the sum of these two ratios plus one will yield the same value for this third ratio as if it had been

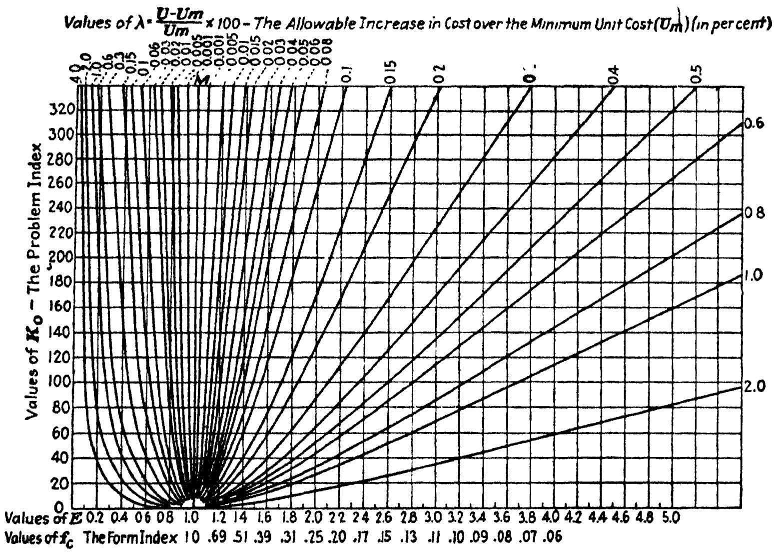


FIG. 135.—Where greater accuracy is desired, or where peculiar conditions cause some doubt as to the reliability of the assumption of a form index of ⅔, this chart may be used. The decimal value of (f_c) is read from the bottom scale and used in the selection of the proper formula.

determined separately. Then, by an inspection of the values for these ratios, the single element which constitutes the greater part of the total value, should all three elements be combined, can be promptly selected.

"Naturally, if two of the elements in the problem are to be disregarded, their omission will produce results which will vary to some degree from the true lot size that would have been obtained by the use of the general equations. To what extent are these variations permissible? Since the denominator of a simplified formula will be smaller than that where all elements

are employed, the lot size will be larger than that which should theoretically be used. This is interesting, because it becomes evident that the use of simplified formulas will have practically no adverse effect upon the economic production quantity, as a slightly larger value will still be in the economic range of production. However, a more dangerous situation develops with regard to their use in determining the minimum cost quantity, because the approximate value due to simplification will fall outside the economic range, and thus the production cost will not permit the profit normally anticipated.

"Accordingly, some limit should be established for the selection of elements, which will prevent too great an encroachment upon the profit margin or, in regard to the economic quantity, too little opportunity properly to conserve capital. This limit should indicate to what extent the value of the denominator in either one of the general formulas may be diminished in order to permit the selection of the single element, if possible, which will assure the requisite degree of accuracy for the resulting simplified form. From a study of a large number of cases, it has been found that a reliable approximation for all problems can be obtained when the summation of the ratios representing the elements in a simplified form is two-thirds the summation of the three basic ratios together. However, in order to understand this situation properly, it should be recognized that the degree of approximation really depends upon the nature of the problem and the extent to which the minimum cost can be increased to permit the production of a quantity slightly larger than that which would be actually produced to obtain this lowest cost of all.

"If the ratio used as a measure of the approximation in accordance with the elements actually employed be designated as the 'form index,' it can be stated in turn that the limiting value for the form index can be computed from the maximum permissible increase in unit cost and the 'problem index.' The value of the first item must necessarily be determined by executive policy, and the value of the second depends upon the proportion which the total preparation costs bear to the total ultimate unit cost and will be a constant for any problem. These facts will be of much assistance in the choice of a simplified form, because it can be shown that when the problem index is small a greater amount of care must be taken in selecting the

appropriate elements than when it is large. Thus, if it is found that the total preparation cost is less than one-half of 1 per cent of the total ultimate unit cost, a reasonably large degree of approximation is permissible even for a relatively small permissible increase in cost, normally one-tenth of 1 per cent of the total ultimate unit cost, and then a form index of four-tenths can be employed in place of two-thirds, as before. Such latitude should permit the choice of the simplest possible formula for the determination of the lot size and give ample assurance that the variation from the true lot size will in no way jeopardize the manufacturing profit or policies.

"Often, a general survey of the methods of production and the characteristics of each unit of production will show that all lot-size computations in a given plant may utilize the same general type of simplified formula. Similarly, certain industries will employ the same simplified formula so that, once the most adaptable form has been chosen, it will be necessary to be on the watch only for cases which are exceptions to the rule. These exceptions alone will need a separate determination of the correct formula. For the most part, familiarity with the method of making these computations as illustrated in the calculation sheets (Table XXXVII) will permit anyone to ascertain, without having to perform the detailed calculations, which of the simplified expressions should be employed. If any of the computations are found necessary, reliable values for the index ratios can be obtained by the use of a slide rule, as no number need be read to any greater degree of accuracy than that given by two significant figures.

"The calculation sheets have been devised for use in any planning or production-control department, and the procedure has been so arranged that any clerk or subordinate can follow the various steps without a particular knowledge of mathematics or a specialized engineering training. It will be noticed that these sheets have been divided into two parts, the second one of which is optional. The first, for general use, outlines the procedure for the selection of simplified forms of the general formulas. The second provides means for determining the maximum allowable variation, by establishing the correct limit for the form index, should the arbitrary value of two-thirds appear at any time to be inappropriate. Because any variation from the true economic production quantity caused by simpli-

TABLE XXXIX.—SIMPLIFIED FORMULAS

General form	Conditions for use
$Q_s = \sqrt{\frac{PS}{K_s k_{r1}}}$	when index ratio R_s is chosen.
$Q_w = \sqrt{\frac{PS}{K_w k_{r1}}}$	when index ratio R_w is chosen.
$Q_v = \sqrt{\frac{PS}{K_v}}$	when index ratio R_v is chosen.
$Q_{sw} = \sqrt{\frac{PS}{(K_s + K_w)k_{r1}}}$	when both index ratios R_s and R_w are chosen.
$Q_{sv} = \sqrt{\frac{PS}{K_s k_{r2} + K_v}}$	when both index ratios R_s and R_v are chosen.
$Q_{wv} = \sqrt{\frac{PS}{K_w k_{r3} + K_v}}$	when both index ratios R_w and R_v are chosen.

where

$$K_s = \frac{ci}{2}\left[1 - \frac{S}{D}\left(1 - \frac{1}{n}\right)\right]$$

$$K_w = \left(\frac{m + c}{2}\right)Sti$$

$$K_v = \frac{sb}{h}\left[1 - \frac{S}{D}\left(1 - \frac{1}{n}\right)\right]$$

for the economic production quantity Q_e

$$k_{r1} = \left(1 + \frac{r}{i}\right)^2$$

$$k_{r2} = 1 + 2\frac{r}{i} + \frac{r^2}{i^2\left[1 + \frac{2sb}{ihc}\right]}$$

$$k_{r3} = 1 + \frac{2r}{i} + \frac{r^2}{i^2\left\{1 + \frac{2sb\left(\frac{1}{S} - \frac{\left(1 - \frac{1}{n}\right)}{D}\right)}{iht\,(m + c)}\right\}}$$

and

$k_{r1}, k_{r2}, k_{r3} = 1$ (unity) for the minimum cost quantity Q_m.

fication will in no way impair the expected profits, the elements employed in its determination need not be separately chosen; those which apply to the minimum cost quantity may be employed in this relation with equal satisfaction.

"Even though simplification introduces certain approximations in the determination of the lot size, it also provides a short-cut method for computing the true values of the minimum cost quantity or the economic production quantity. This can

be accomplished through the use of the form index as a corrective factor, because it represents the relation of the data employed in a simplified form to that required to obtain the exact size of the lot from one of the general formulas. Accordingly, any manufacturer can adopt for the solution of all problems the simplest one of the formulas for determining the lot size and then correct the results obtained by multiplying the approximate production quantity by the square root of the form index f_c. For example, if the lot size be computed from the equation

$$Q_{ms} = \sqrt{\frac{2PS}{ci}}, \tag{9}$$

the minimum cost quantity Q_m may be accurately calculated from

$$Q_m = \sqrt{f_c} \times Q_{ms}$$

$$\text{where } f_c = \frac{1}{1 + R_u + R_v}, \tag{10}$$

and the economic production quantity Q_e may be similarly obtained from

$$Q_e = \sqrt{f_e'} \times \frac{Q_{ms}}{\left(1 + \frac{r}{i}\right)} \tag{11}$$

$$\text{where } f_e' = \frac{1}{(1 + R_w) + \frac{R_v}{k_r}}$$

$$\text{and } k_r = \left[1 + \frac{2r}{i} + \frac{r^2}{i^2} \times \frac{1 + R_u}{1 + R_u + R_v}\right]$$

APPENDIX C

DEPRECIATION DATA

"The rates recommended below are rates that will stand the test of the income tax laws and have been accepted by the Bureau of Internal Revenue in the settlement of a great number of tax cases. At the same time they are rates that will assure the industry adequate allowances for cost-finding purposes.

Item	Life, years	Rate, per cent
Real estate improvements.		
Roadways:		
Brick	8 to 10	10
Concrete	10	10
Macadam	6 to 7	15
Walks:		
Brick and cement	10	10
Wood, charge to expense, not over	2	50
Fences and Walls:		
Iron and wire	10	10
Wood or wood and wire, etc	2 to 3	50 to 33⅓
Fences made of these materials are usually in bad shape before the end of the second year or so. Therefore, it would be more proper to consider all such outlays as charges to expense immediately. In no case depreciate for more than 2 or 3 years.		
Railroad tracks and sidings	20 to 25	4 to 5
Railroad tracks must be kept in A1 condition at all times. The repairs, replacements, and general maintenance should be expensed in all cases. In some cases depreciation charged at the same rate as the buildings they serve would be entirely justified.		

All of the above items are subject to the elements, and this factor should be considered. All renewals, repairs, replacements, moving, and all other such outlays should be charged to expense at once.

Item	Life, years	Rate, per cent
Buildings:		
Concrete, reinforced	30	3½
Concrete block, etc	20	5
Brick	20	5
Wooden	10	10
Steel frame, corrugated iron walls, etc	7 to 8	15
Building equipment:		
Plumbing: The rough usage of plumbing and fixtures in machine shops and the many frequent changes and moves warrants not over a ten-year life	10	10
Electrical wiring: Due to the numerous changes that are constantly being made a 5-year life is considered about normal	5	20
Elevators, freight and passenger	10	10
Sprinkler systems	20	5
Heating and ventilating, same class as plumbing	10	10
All of these items are subject to many changes, replacements and maintenance charges, and constant moving around to suit new operating conditions. All changes, replacements, and improvements should be charged to expense immediately.		
Machinery:		
Machine tools:		
Large, heavy	10	10
Small, light	8	12½
Automatic	6 to 7	15
It is very obvious that the larger and heavier type of machine tools have a longer economic and useful life than the smaller and automatic machines. A shop that has a large number of automatic machines should charge a higher rate for those machines, as the actual wear and tear is much greater and the obsolescence is more acute. The heavier machines are not subject to the same degree of obsolescence as the smaller machines and the automatics. The three distinct classifications are therefore recommended for most machine tool plants.		

Item	Life, years	Rate, per cent
Machinery: (*Continued*)		
A fourth classification, at a lower rate of 5 or $7\frac{1}{2}$ per cent, might be added to cover the extremely large machines found in a few of the shops making the largest type of equipment.		
No rate of less than 10 per cent should apply to the general classes of machine tool equipment commonly in use in the majority of plants. The lower rate is the exception rather than the rule.		
Motors, controllers, and electrical equipment, individual-line motors, etc.	10	10
Cranes, electric, overhead traveling, and craneways, hydraulic, steam, etc., and lifting magnets	12 to 15	$7\frac{1}{2}$
Hoists, jib cranes, hand cranes, electric and chain hoists, derricks, etc.	6 to 8	15
Shop equipment:		
Hangers, pulleys, and shafting (due to obsolescence)	5	20
Furnaces and forges	5 to 7	15 to 20
Lockers, bins, and benches:		
Wooden, charge to expense	0	0
Steel, of a stationary nature, not over	4	25
Shop office equipment	4	25
Shop office equipment is subject to unusual rough usage and depreciates very rapidly.		
Blueprinting machines and equipment	10	10
Breast drills and other electrically or automatically operated hand tools should be charged to expense.		
Small tools:		
Taps, reamers, drills, files, saws, chisels, chucks, etc., should be charged to expense immediately as issued to shop.		
Dies, jigs, and fixtures:		
Should be *expensed* immediately. If advisable to capitalize, they should be charged off over a period not to exceed three years, or spread over a certain number of machines that would be normal to build and ship in the three-year period.		
Patterns and drawings:		
Should be *expensed* immediately. In cases where it is found advisable to capitalize, they should be spread over not more than a 3-year period the same as dies, jigs, and fixtures.		

Item	Life, years	Rate, per cent
Belting:		
Belting should be charged off to *expense* at once in all cases.		
Power-house equipment:		
Boilers, Engines, Generators — composite rate	10	10
Office furniture and fixtures:		
Desks, chairs, and other furniture	7 to 10	15
Mechanical office equipment:		
Typewriters, adding machines, check writers, printing machines, etc	3	33⅓
Automobiles:		
Trucks:		
Heavy	4	25
Light	3	33⅓
Passenger cars		3 per cent a month
Automatic signal systems	7½	15
Hospital equipment	5 to 7	15 to 20
Restaurant equipment, fixed	5 to 7	15 to 20
This classification should include only such items of equipment as are fixed, such as ranges, boilers, tables, refrigerators and the like. Dishes, pots and pans, and other table and kitchen ware should be charged to expense.		
Second-hand equipment:		
Consideration should be given to the depreciation rates that are to be used and applied to used or second-hand equipment that is purchased or traded in and installed in the plant. It is self-evident that such items of equipment will have served a great part of their useful and economic life before they come into your plants. Therefore such items should not be put into a general machinery account and depreciated at the regular rate charged off on new machinery. Rates that in many cases are many times higher than the rate for new machinery should be used. Second-hand equipment acquired usually does not have a life of more than 4 or 5 years at the most and depreciation rates should be set accordingly."[1]		

[1] *N.A.C.A. Bull.* p. 1411, Aug. 15, 1928. By permission of National Association of Cost Accountants.

APPENDIX D

THE DESIGN OF PRINTED FORMS

Forms are used to give information, to indicate methods of procedure, and to aid in collecting and recording information by making filing easier and the information more compact and convenient to use. The form saves time in recording and taking off information.

1. Use and Purpose.

In designing a form it is first necessary to know and understand the uses to which the form will be put. If two or more departments will use the form (either entering or taking off information), care should be used to meet the requirements of all concerned.

2. Contents.

A list of all information that will appear on the form should be made and then the different items should be studied and grouped in the sequence in which they are to appear on the printed form.

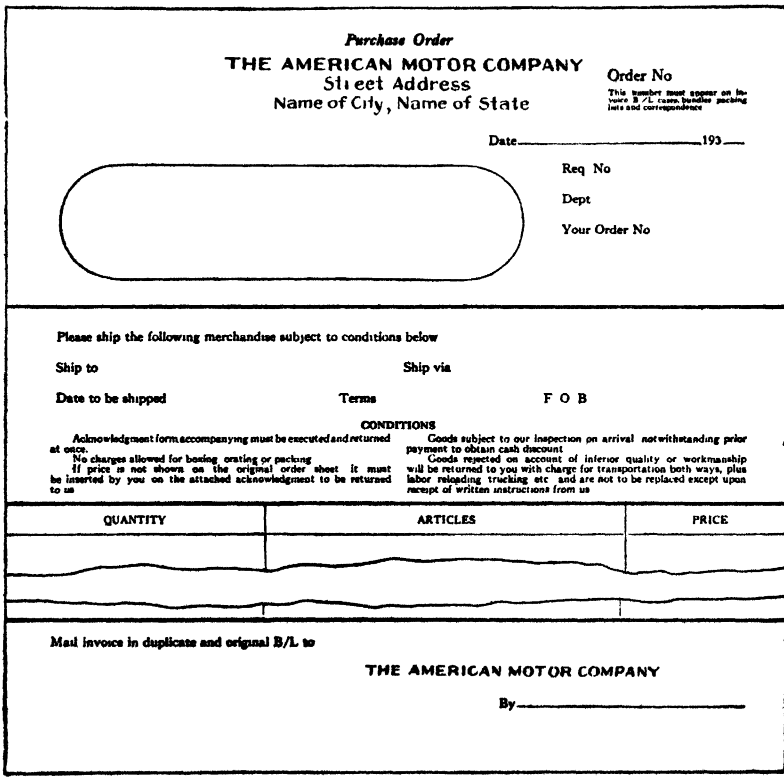
3. Make-up of the Form.

It is desirable to enter information on the form in the order that it is obtained and in the order that it will be taken off. If it is impossible to do this, preference should be given to entering the information, because more effort is exerted in this operation and there is greater chance for error. There are several subjects that should be considered here:

a. Filing.—The most important location on a form is at the upper right-hand corner (for some filing systems the lower right-hand corner is most important), and this space should be used to record information used in filing and sorting. The use of different colors of paper may aid in sorting and filing. If not more than duplicate or triplicate copies are required, different colors can be used to good advantage; but if many

copies are needed, it is often better practice to use one color paper for all and number each copy. Dark shades or colors may make it difficult to read the information recorded on the form.

b. Heading.—It is desirable to give every form a name, and this is often placed at the top as a heading. If this space is considered too valuable and if it can be used to better advantage for other purposes, then the form name might be located at some other place on the form.



Purchase Order

THE AMERICAN MOTOR COMPANY
Street Address
Name of City, Name of State

Order No
This number must appear on invoice B/L cases, bundles packing lists and correspondence

Date ________________ 193__

Req No

Dept

Your Order No

Please ship the following merchandise subject to conditions below

Ship to   Ship via

Date to be shipped   Terms   F O B

CONDITIONS

Acknowledgment form accompanying must be executed and returned at once.

No charges allowed for boxing crating or packing

If price is not shown on the original order sheet it must be inserted by you on the attached acknowledgment to be returned to us

Goods subject to our inspection on arrival *not* withstanding prior payment to obtain cash discount

Goods rejected on account of inferior quality or workmanship will be returned to you with charge for transportation both ways, plus labor reloading trucking etc and are not to be replaced except upon receipt of written instructions from us

QUANTITY	ARTICLES	PRICE

Mail invoice in duplicate and original B/L to

THE AMERICAN MOTOR COMPANY

By ________________

FIG. 136.—Standard purchase order. The arrangement of information on this form conforms to the style recommended by the National Association of Purchasing Agents. The form should be printed on a sheet 8½ in. wide, and either 7, 11 or 14 in. long.

c. Duplication.—Information that will appear alike on several different forms should have the same relative position on the form. This makes it possible to use some duplication method or process for recording the data on several forms at one time.

For example, it may be desirable to place the part number, the department number, and the number of pieces in the lot on the move ticket, the time ticket, and the inspection ticket. If the space for this information appears at the same place on each of the three forms, then the information can be recorded on or filled in on all three copies at once by the use of carbon paper or other means of duplication.

d. Amount of Space.—The amount of space required for each item will depend on whether the form will be made out on a typewriter or by handwriting. The typewriter spaces 0.1 in.; therefore, the vertical rules should be in units of 10 spaces to the inch. The horizontal rules should be 3 or 6 to the inch depending upon whether single or double spacing is desired. Often rulings are omitted entirely when the typewriter is to be used. When handwriting is used, approximately twice as much space will be needed. It is unwise to crowd a form. The size and style of type used in printing will to some extent determine the space required. Gothic type should be used on all forms, as it is easy to read, blueprint, or photostat, and it looks well.

e. Instructions.—If instructions are required to explain the use of the form or the exact procedure in filling it out, this information may be printed on the form in fine print at the bottom of the sheet.

f. Signatures.—It is common practice to place signatures in the lower right-hand corner of the sheet. However, if other positions seem logical and more convenient, they can be used. Often an initial or initials of the person will take the place of a signature and will save space on the form.

g. Checking.—Squares may be used for checking information instead of providing space for writing out the information, as:

Ship by:

Express	
Freight	
Parcel post	

Date

Month	Day	Year

h. Form Number.—The form number should be placed in the lower right-hand or upper left-hand corner or where the space will be the least valuable. The number should appear at the same place on all forms. The form number will indicate the

department number, the quantity, and the date (month and year) printed. The form number E 25 M 2-28 means "Engineering Department, 25,000 forms printed in February, 1928."

4. Size.

Two things determine the size of the form: First and by far the more important, there must be sufficient space for recording all the information, and then the size to some extent will be determined by the sizes that can be cut without waste from standard sizes of sheet paper. The standard sizes recommended by the U. S. Bureau of Standards and adopted by most paper manufacturers are:

Inches		Inches
17 by 22	Double size	22 by 34
17 by 28		28 by 34
19 by 24		24 by 38

These sizes make it possible to cut the following usable sizes with little or no waste:

Inches	Inches
3 by 5	8½ by 11
4 by 6	8½ by 14
5 by 8	11 by 17

5. Quality of Paper.

In selecting the quality of paper to be used, there are several use requirements to be considered. The "Handbook of Quality-Standard Papers,"[1] published by the American Writing Paper Company, gives the following analysis:

Treatment.—The amount and severity of handling, folding, or exposure to which the paper is to be subjected. This use factor is met by that property of the paper that has been defined as strength.

Longevity.—The length of time for which the paper must resist deterioration. Longevity is determined by the degree of permanence required of the paper. Legal documents and records, for example, must resist deterioration for a long period of time. The ability to withstand deterioration marks the property of life in a paper.

Appearance.—The character of sense appeal in the paper itself. As a use factor, appearance is obtained in the printed

[1] P. 98.

piece by the proper consideration of that property of the paper that has been defined as appearance.

Impress.—The mechanical method of applying the reading matter, illustrations, decorations, or rulings. Impress may be limited to one kind, but usually a combination of several kinds is used. Each requires consideration of different properties in the paper. In offset printing, shrinkage is a factor; in mimeograph paper, absorbency; and for pen and pencil writing, erasive qualities and non-absorbency are important. Finish, weight, color, opacity, and stiffness of paper must also be considered with respect to the type of impress and the method of its application.

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